THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant. —*Novum Organum, Præfatio.*

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PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES,

BESIDES THOSE IN THE PLATES.

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THE

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1. *On a* New Specimen *of the* Chimæroid Fish, *Myriacanthus paradoxus*, *from the* Lower Lias *near* Lyme Regis (Dorset).

By Arthur Smith Woodward, LL.D., F.R.S., F.L.S., F.G.S.

(Read November 22nd, 1905.)

[Plate I.]

In 1871 the late Sir Philip Egerton[1] communicated to the Geological Society an account of part of a fossil Chimæroid from the Lower Lias of Lyme Regis, remarkable as exhibiting a peculiar prolongation of the snout like that of the existing *Callorhynchus*. He named the specimen *Ischyodus orthorhinus*. In the following year he described[2] the somewhat anomalous dentition of a much larger Chimæroid fish from the same formation and locality, and regarded it as representing a previously-unknown genus and species, *Prognathodus Guentheri*. With the aid of additional specimens in 1889, I was able to prove[3] that the dorsal fin-spine of the so-called '*Ischyodus orthorhinus*' was identical with an ichthyodorulite which had been named *Myriacanthus granulatus* by Louis Agassiz in 1837[4]; while the dentition of the same fish, when satisfactorily preserved, agreed generically with that known as *Prognathodus*. I therefore

[1] 'On a New Chimæroid Fish from the Lias of Lyme Regis (*Ischyodus orthorhinus*)' Quart. Journ. Geol. Soc. vol. xxvii (1871) pp. 275–78 & pl. xiii.

[2] 'On *Prognathodus Guentheri*, Egerton, a new Genus of Fossil Fish from the Lias of Lyme Regis' *ibid.* vol. xxviii (1872) pp. 233–36 & pl. viii.

[3] 'On the Myriacanthidæ—an Extinct Family of Chimæroid Fishes' Ann. & Mag. Nat. Hist. ser. 6, vol. iv (1889) pp. 275–80; see also 'Catalogue of the Fossil Fishes in the British Museum' pt. ii (1891).

[4] 'Recherches sur les Poissons fossiles' vol. iii (1837) p. 40 & pl. viii *a*, fig. 16.

inferred that the larger ichthyodorulite named *Myriacanthus paradoxus* by Agassiz,[1] belonged to the same fish as the larger dentition named *Prognathodus Guentheri*; and in this determination I was confirmed by the discovery of a very similar spine in association with a *Prognathodus*-like dentition in the Lithographic Stone of Bavaria.[2] The name *Myriacanthus* thus acquired a definite zoological meaning, and no longer denoted a mere ichthyodorulite of doubtful relationships.

Until the present time, however, the spine named *Myriacanthus paradoxus* has not been found in direct association with the dentition described as *Prognathodus Guentheri.* The expected discovery has at last been made, and as the new specimen displays some additional features of interest, it seems worthy of special description. The fossil in question (Pl. I, figs. 1–4) was lately obtained by Mr. S. Curtis from the Lower Lias of Black Ven, and has been acquired by the British Museum (Natural History), which already possesses the specimens previously described. It shows the dorsal fin-spine in direct connection with a mass of decayed cartilage, dermal plates, and teeth; and there can be no doubt that it represents the crushed and partly-scattered remains of a single individual.

Much of the cartilage in the fossil is calcified in small polygonal tesseræ, which are especially large and conspicuous on the rostral prolongation (*r*), and were originally mistaken by Egerton for shagreen. Part of the ascending limb of the pectoral arch (*pct*) is distinguishable among the confused remains.

The dental plates are but slightly displaced, and are sufficiently well preserved for identification. The right palatine (*r.pa*) is exposed from the upper attached face, but its thin ascending externo-lateral edge is crushed inwards. Allowance being made for the small distortion, it exhibits the shape and proportions of the corresponding plate already described in the so-called '*Prognathodus Guentheri.*' The left palatine (*l.pa*) is less satisfactorily exposed from its lower or oral face, but exhibits the usual lack of the tritor on an oblique patch in its anterior half.[3] One of the vomerine plates (*v*) shows only the inner face by which it was apposed to its fellow of the opposite side. The hinder part of the lower border of the right mandibular dental plate is just visible (*md*), and the displaced presymphysial tooth (*ps*) is well shown from the inner aspect. The latter tooth (Pl. I, fig. 2) tapers rapidly to its inserted end, while its inner face is flattened, marked only by feeble transverse lines of growth, and bordered on each side by a rounded raised rim. In cross-section, the outer part of the tooth shows cancellated structure, and the tritor is confined to a thin inner layer.

[1] 'Recherches sur les Poissons fossiles' vol. iii (1837) p. 38 & pl. vi.

[2] K. A. von Zittel, 'Handbuch der Paläontologie' vol. iii (1887) pp. 113–14 & fig. 126. See also J. Reiss, Palæontographica, vol. xxxiv (1887) p. 21, pl. ii, figs. 9–11 & pl. iii, figs. 1–10.

[3] See 'Catalogue of the Fossil Fishes in the British Museum' pt. ii (1891) pl. ii, fig. 1.

The frontal spine or tenaculum (*t*) is only partly shown in left side-view: but it was obviously expanded at the base, and tapered to a point distally. It is relatively small, and its size denotes that the animal to which it belonged was immature.[1] The teeth and fin-spine, indeed, are only about two-thirds as large as those in the larger and best-known examples of the same species. Scattered beneath the anterior half of the tenaculum and farther forwards on the rostrum are numerous small hooklets, which doubtless originally assisted in the prehensile functions of the spine. Each of these hooklets (Pl. I, fig. 3) is a polished recurved point fixed on an expanded base, which is marked by radiating furrows. Very minute hooklets and stellate tubercles of similar shape (fig. 3 *a*) are also visible in a patch on the anterior part of the fossil, and perhaps at the base of the dorsal fin-spine. They have already been noticed in the skin of the allied genus *Chimæropsis* from the Bavarian Lithographic Stone.[2] It is curious that there are no traces of calcified rings marking the course of sensory canals.

In addition to the frontal spine and hooklets just described, there are also remains of two, or perhaps three, pairs of the tuberculated dermal plates, which have already been noticed in other specimens. The most anterior pair preserved (I) is that of which one plate is well shown in the type-specimen of *Prognathodus Guentheri* described by Egerton. The hollow, ridged plate (fig. 4) is ornamented by rows of smooth tubercles which radiate down the sides from the summit; and its ridge is surmounted by large, longitudinally striated spikes, of which only two are exhibited in the new fossil, but of which there are four in a specimen in the Museum of Practical Geology (fig. 5).[3] One of a pair of narrow ridged plates is exposed from its attached face farther back in the fossil (III); and this is evidently identical with a plate represented in another specimen in the British Museum.[4] At the base of the tenaculum there is part of another plate (II), which may be the fellow of that just mentioned, or may belong to an intermediate pair.

The straight dorsal fin-spine, exposed in left side-view (*d.f*), is much crushed, and has accidentally lost nearly all its thorn-shaped denticles; but it is interesting, as displaying for the first time the complete base of insertion. This base is comparatively short, and tapers to a bluntly-pointed lower extremity. The very slender apical part of the spine is almost destitute of tubercles on the sides, but is marked with conspicuous longitudinal striations.

The new fossil thus warrants the conclusion that *Myriacanthus* is a Chimæroid closely similar to the Upper Jurassic *Chimæropsis*, with (i) a median chisel-shaped tooth in front of the lower jaw; (ii) a few tuberculated dermal plates on the head; and (iii) a tuber-

[1] On the growth of the frontal spine in male Chimæroids, see A. Günther, 'Report on the Deep-Sea Fishes,' *Challenger* Reports, vol. xxii (1887) p. 12.

[2] K. A. von Zittel, 'Handbuch der Paläontologie' vol. iii (1887) p. 113.

[3] B. Dean, 'American Geologist' vol. xxxiv (1904) p. 52 & pl. ii, fig. C.

[4] 'Catalogue of Fossil Fishes' pt. ii (1891) pl. ii, fig. 2.

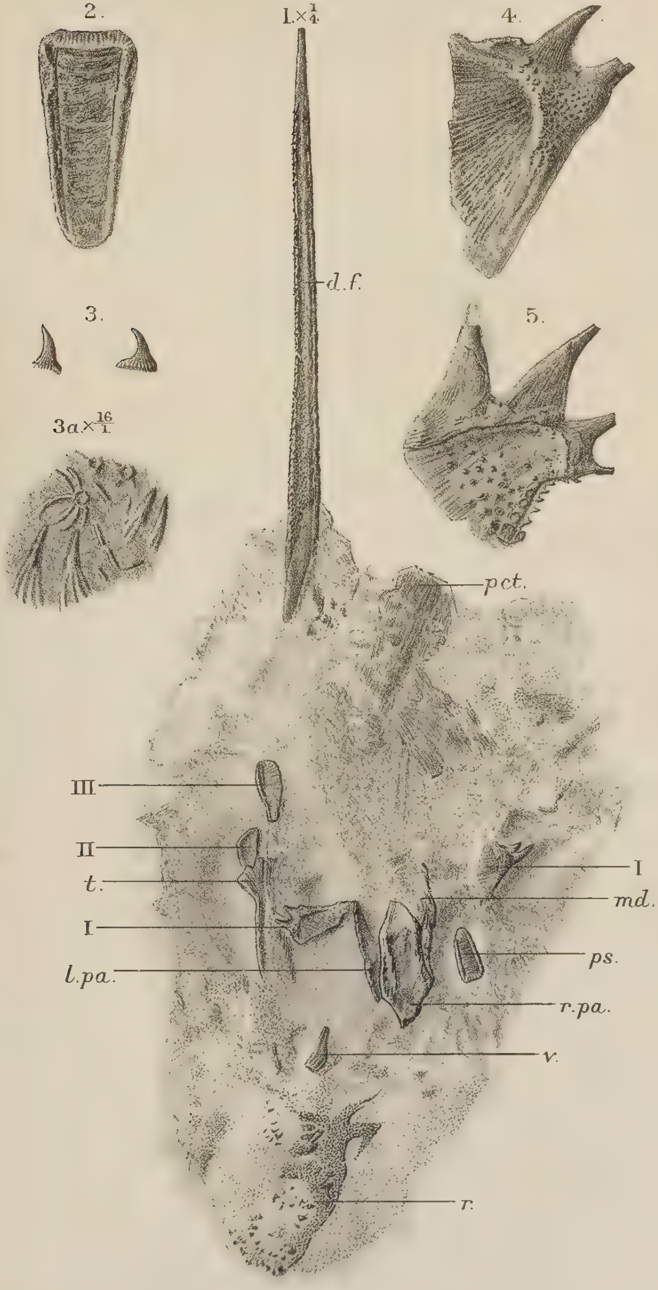
culated dorsal fin-spine. In these three respects it differs from all other known Chimæroids—even from the comparatively-primitive types which have been discovered during recent years in the Japanese seas.[1] The Myriacanthidæ, in fact, have still no nearer ally than *Callorhynchus*, with which Egerton originally compared his so-called '*Ischyodus orthorhinus*.'

EXPLANATION OF PLATE I.

Fig. 1. *Myriacanthus paradoxus*, Agassiz; remains of anterior portion of fish, with dorsal fin-spine, one-quarter natural size.—Lower Lias; Black Ven, Lyme Regis. [Brit. Mus. no. P. 10130.] *d.f*, dorsal fin-spine; *l.pa*, left palatine dental plate; *md*, right mandibular dental plate; *pct*, cartilage of pectoral arch; *ps*, presymphysial tooth; *r*, rostral cartilage; *r.pa*, right palatine dental plate; *t*, frontal spine or tenaculum; *v*, vomerine dental plate; I, II, III, dermal plates.

2. Presymphysial tooth of the same specimen, inner aspect, natural size.
3. Dermal hooklets from the rostrum of the same specimen, two being of the natural size, and the cluster (3 *a*) enlarged sixteen times.
4. Dermal plate I of the same specimen, natural size.
5. Corresponding dermal plate of another specimen of the same species, natural size. [Museum of Practical Geology, Jermyn Street, no. 1545.]

[1] S. Garman, 'The Chimæroids, especially *Rhinochimæra* & its Allies.' Bull. Mus. Comp. Zool. Harvard, vol. xli, no. 2 (1904), with fifteen plates.



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MYRIACANTHUS PARADOXUS.

2. *The* DONCASTER EARTHQUAKE *of* APRIL 23RD, 1905. By CHARLES DAVISON, Sc.D., F.G.S. (Read November 22nd, 1905.)

[PLATE II.—MAP.]

I. INTRODUCTION.

ON April 13th, 1902, a slight earthquake occurred in the north of Lincolnshire. Its intensity was not more than 4, and the area disturbed by it included about 600 square miles. The shock was of the simplest character, lasting on an average for 4 seconds, and consisting of a single series of vibrations, which increased in intensity to a maximum and then died away.[1] Though of little consequence when considered as an isolated event, the shock derives interest from its probable connection with the much stronger twin-earthquake which occurred in the same district three years later, on April 23rd, 1905.[2]

On this day, there were two undoubted earthquakes, namely:—

(*a*) About 1.30 A.M.
(*b*) 1.37 A.M. (principal earthquake).

In addition to these, several disturbances of uncertain seismic origin are reported:—

April 23rd, about 1.39 A.M.: Barton-on-Humber.—A very slight shock, similar to that of the principal earthquake, and accompanied by a sound like distant thunder.

April 23rd, about 2.5 A.M.: Farnsfield and Normanton-on-Trent.—A slight shock, without any attendant sound, was felt at these places, both of which are more than 15 miles from the principal epicentre.

At Farndon (near Newark) subterranean noises are said to have been heard on several occasions, especially on April 27th, at 11.30 P.M., and on April 29th, about midnight.

II. FORE-SHOCK.

(*a*) April 23rd, about 1.30 A.M.

Number of records 2, from 2 places.

A slight shock was felt at Epworth, and a rumbling sound was heard at Norton. Epworth lies between the two portions of the

[1] Geol. Mag. 1904, pp. 536–37.

[2] In the investigation of this earthquake, I have received great and welcome assistance from the following gentlemen, to whom my best thanks are offered:—Dr. Tempest Anderson, F.G.S., Mr. L. W. Bunting (of South Carlton, near Lincoln), Mr. G. Hibberd (of Laughton, near Rotherham), Mr. J. Dennis (station-master at Sutton, near Retford), the Rev. F. S. F. Jannings (rector of Warmsworth, near Doncaster), Mr. T. J. Moore (of Hatfield, near Doncaster), Mr. E. P. Richards (of Hathersage), and the Rev. A. P. Woodhouse (vicar of Tuxford), and the superintendents of police of the Dewsbury, Eckington, and Pocklington Divisions. The expenses of the investigation were defrayed from a grant received from the Government Research-Fund.

isoseismal 7 of the principal earthquake, and Norton about 8 miles north of Doncaster. At about the same time, a rumbling noise was heard at Bassingham (near Lincoln), and a shock was felt at North Collingham (near Newark). In the absence of records from intermediate places, it is uncertain whether the last two observations refer to a fore-shock connected with the Doncaster earthquake.

III. Principal Earthquake.

(b) April 23rd, 1.37 A.M.

Intensity, 7; centre of south-western portion of isoseismal 7, lat. 53° 26·3′ N., long. 1° 1·2′ W.; centre of north-eastern portion of isoseismal 7, lat. 53° 36·5′ N., long. 0° 43·7′ W. Number of records, 1428, from 662 places, and 68 negative records from 66 places.

Time of Occurrence.

Excluding estimates that are given approximately, the total number of records of the time is 695. Of these, 110 are regarded by their observers as accurate to the nearest minute. The average of the latter is 1.37 A.M., and, as the averages for the zones included between successive isoseismals differ from this by less than half a minute, it is probable that the time of occurrence at the epicentre was almost exactly 1.37 A.M.

Isoseismal Lines and Disturbed Area.

The five continuous curves on the map of the earthquake (Pl. II) are isoseismal lines of intensities 7 to 3; the broken-and-dotted line represents the boundary of the area disturbed by the earthquake of April 13th, 1902.

The isoseismal 7 consists of two portions, which are approximately circular in form. The south-western and larger portion, which is the most accurately drawn of the series, is $18\frac{1}{4}$ miles long from north-east to south-west, $17\frac{3}{4}$ miles wide, and 244 square miles in area. Its centre lies half a mile north of Bawtry, in lat. 53° 26·3′ N., long. 1° 1·2′ W. The course of the north-eastern portion is somewhat uncertain towards the south-east, but probably does not vary by more than a mile from the true position. As drawn, it is $9\frac{1}{4}$ miles long from north-east to south-west, $8\frac{3}{4}$ miles wide, and 63 square miles in area. Its centre is about 4 miles east of Crowle, in lat. 53° 36·5′ N., long. 0° 43·7′ W., and lies 17 miles north-east of the former. The centre of the disturbed area of the earthquake of 1902 is in lat. 53° 33·4′ N., long. 0° 41·5′ W., or about $3\frac{1}{2}$ miles south-south-east of the centre of the north-eastern portion of the isoseismal 7.

The next isoseismal, corresponding to intensity 6, is roughly elliptical in form, 58 miles in length, 44 miles in width, and 2050 square miles in area. The direction of its longer axis is E. 38° N. and W. 38° S. Its distances from the south-western portion of the isoseismal 7 are 14 miles on the north-west side and $12\frac{1}{2}$ miles on

the south-east side, and, from the north-eastern portion of the same curve, 14 and 16 miles respectively.

The remaining isoseismals are somewhat less accurately drawn, and, in parts, may possibly vary as much as 2 or 3 miles from their true position. The deviation cannot, however, be of much consequence. The isoseismal 5 is 90 miles long from north-east to south-west, 76 miles wide, and contains 5300 square miles; its distance from the isoseismal 6 is 14 miles on the north-west, and 18 miles on the south-east side. The isoseismal 4 is 126 miles long from north-east to south-west, 108 miles wide, and about 10,700 square miles in area, and is distant 16 miles in both directions from the isoseismal 5. The isoseismal 3 is 166 miles long from north-east to south-west, 130 miles wide, and about 17,000 square miles in area, its distance from the isoseismal 4 being 14 miles towards the north-west and 21 miles towards the south-east. I have also received records from several places outside the isoseismal 3 —from Liverpool, Lingen (in Herefordshire), Hugglecote and Winchcombe (in Gloucestershire), Soham (in Cambridgeshire), and Norwich; but I do not feel sure that the movements observed at these places were connected with the Doncaster earthquake. The area apparently disturbed by the earthquake was therefore about 17,000 square miles.

Nature of the Shock.

The twin-character of the shock was clearly recognized throughout a district overlapping the isoseismal 5 by a few miles in every direction, and was sensible to some observers as far as, and in three cases beyond, the isoseismal 4. Over the whole disturbed area, 32 per cent. (or roughly 1 in 3) of the observers who noticed closely the nature of the shock detected either two maxima in a continuous series of vibrations, or two detached series of vibrations separated by an interval of a few seconds. The percentage varies in different districts, being 31 within the isoseismal 7, 38 between the isoseismals 7 and 6, 32 between the isoseismals 6 and 5, and 14 between the isoseismals 5 and 4. These variations and the comparatively-small percentage are due: (1) at places within the isoseismal 5, and especially near the epicentres, to the perception of a continuous tremor between the two parts of the shock; and (2), at places outside the isoseismal 5, to the enfeeblement of the vibrations composing the weaker part. Thus, at Balne (9 miles north of Doncaster), the movement was continuous and contained two maxima, the first of which was the stronger; at Sheffield, the intervening tremor was less sensible, and the shock consisted of two detached parts separated by an interval of one second, the first being slightly stronger than the second; at Thornton Curtis (9 miles north-east of Brigg), two series were felt, of which the second was the stronger, the interval between them being 3 or 4 seconds, and also two distinct sounds were heard, of which the second was the louder and separated from the first by 2 or 3 seconds; and, lastly, at

Humberstone (2 miles east of Leicester), the shock consisted of a single series of vibrations, lasting from 3 to 4 seconds, the intensity of which increased to a maximum and then died away.

Owing perhaps to the variable perception of the intervening tremor, the estimates of the length of the interval between the two parts of the shock lie between rather wide limits. The average of 110 estimates is $3\frac{1}{2}$ seconds. There is, however, no evidence of the existence of a synkinetic band,[1] within which the two parts of the shock coalesced, bordered by bands in which the shock consisted of two maxima of intensity. Thus, the interval between the occurrence of the two impulses must have been greater than the time required for the vibrations to travel from one focus to the other.

That the two parts of the shock did not differ greatly in intensity is shown by the magnitude of the area over which the twin-shock was felt, and also by the very variable testimony of observers with regard to the relative intensity of the two parts, each part being regarded as the stronger by approximately the same number of observers. If we treat all the observations as of equal value, no law in the distribution of relative intensity is apparent; and it is only by rejecting all records, except those made by observers who were awake at the time and who evidently attended carefully to the phenomena, that any such law can be ascertained. It is then seen that the first part of the shock was slightly the stronger over the larger part of the disturbed area; while the second part was the stronger within a small and nearly-circular area indicated by the broken line (*) on the map of the earthquake (Pl. II). This area, which is about 20 miles in diameter, includes the centre of the north-eastern portion of the isoseismal 7, its own centre lying about 6 miles to the north-east.

Origin of the Double Shock.

It is evident that the two parts of the shock originated in two detached foci; though, in the intervening region of the fault, there must have been a slight displacement sufficient to account for the widely-felt tremor connecting the two series of vibrations. The two epicentres cannot be far distant from the centres of the two portions of the isoseismal 7, and are therefore separated by a distance of about 17 miles. It follows, also, from the relative intensity of the two parts of the shock, that the impulse within the south-western focus took place a few seconds before the other and that it was slightly the stronger, the latter inference being confirmed by the larger size of the south-western portion of the isoseismal 7; further, that every point of the disturbed area was reached first by the vibrations from the south-western focus. The second part of the shock was the more intense within the circular region near the north-eastern epicentre, owing to the proximity of the corresponding focus.[2]

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 21.
[2] *Ibid.* p. 28, fig. 3.

Seismographic Record.

The earthquake was registered by the Omori horizontal pendulum at Birmingham, which city is 75 miles S. 28° W. of the principal epicentre. The record is too minute and ill-defined for reproduction, the range or double amplitude of the largest waves (the second, third, and fourth) being less than $\frac{1}{100}$ inch, and corresponding to a movement of the ground of about $\frac{1}{2000}$ inch.[1] The remaining vibrations are represented by mere notches on the trace, and in parts these cannot be separated. Altogether, there appear to be about thirty vibrations in about 15 seconds. The exact time of the first movement I am unable to determine.

Sound-Area.

The boundary of the sound-area is indicated on the map (Pl. II) by the dotted line. Except towards the north-east, it overlaps the isoseismal 4 by a few miles, extending 11 miles beyond it towards the south-west, and falling short of it towards the north-east by 3 miles. It is 135 miles in length, 115 miles in width, and about 12,000 square miles in area.

For a strong earthquake, the sound was heard by an unusually-large proportion of the observers: the percentage of audibility for the whole disturbed area being 93. The same high percentage is also maintained to a considerable distance from the epicentres: being 94 within the isoseismal 7, 94 between the isoseismals 7 and 6, 93 between the isoseismals 6 and 5, 86 between the isoseismals 5 and 4, and 67 between the isoseismal 4 and the boundary of the sound-area. Nor is there any sensible variation with the direction from the epicentres; for, in attempting to draw isacoustic lines by the method employed for the Derby earthquakes of 1903 and 1904, the change in audibility from one square to another was found to be small and irregular.[2] There is no trace of any strengthening of the sound in the directions at right angles to the longer axes of the isoseismals—a result which is in agreement with the absence of a synkinetic band.

Nature of the Sound.

The total number of descriptions of the earthquake-sound is 1061. In 43 per cent. of these, the sound is compared to passing traction-engines, motor-cars, etc., in 29 per cent. to thunder, in 12 to wind, in 4 to loads of stones falling, in 4 to the fall of a heavy body, in 6 to explosions, and in 2 per cent. to miscellaneous sounds. These

[1] It is probable that the actual displacement of the ground was greater than this, for the deposit of soot on the paper clearly hindered the movement of the pendulum.

[2] With a very large number of observations, it would of course have been possible to draw the isacoustic lines. But when, as in this case, the number of records from places within any square is not great and the number of negative records very small, one more or one less negative record causes a considerable change in the percentage of audibility. The irregular variations in audibility are probably to be explained in this manner.

figures agree closely with those obtained for the Derby earthquake of 1904.[1]

The variation in the nature of the sound with the distance from the epicentres is shown in the following table (I), in which the figures are percentages of comparison to the different types for each of the districts mentioned:—

Table I.	Passing vehicles.	Thunder.	Wind.	Loads of stones falling.	Fall of a heavy body.	Explosions.	Miscellaneous.
Within isoseismal 7	34	38	11	3	1	11	3
Between isos. 7 and 6 ...	39	29	11	8	4	8	1
,, ,, 6 ,, 5 ...	48	26	11	3	5	5	3
,, ,, 5 ,, 4 ...	41	31	17	1	2	5	3
,, ,, 4 ,, 3 ...	46	16	38	...	...	...	...

Thus, with increase of distance from the epicentres, there is a marked diminution in the proportion of comparison to sounds of an abrupt or irregular character, and a corresponding increase in those of a smooth or monotonous type.

Time-Relations of the Sound and Shock.

In Table II (below), the letters p, c, and f indicate the number of records per cent. in which each of the principal epochs of the sound (namely, the beginning, the epoch of maximum intensity, and the end) preceded, coincided with, or followed, the corresponding epoch of the shock; the letters g, e, and l show the number of records per cent. in which the duration of the sound was greater than, equal to, or less than, that of the shock.

Table II.	Beginning.			Epoch of Max. Int.			End.			Relative Duration.		
	p	c	f	p	c	f	p	c	f	g	e	l
Within isoseismal 7	84	14	1	...	...	...	16	67	17	82	18	...
Between isoseismals 7 and 6.	76	15	9	27	55	18	10	41	49	76	18	6
,, ,, 6 ,, 5.	68	20	12	31	62	8	11	47	42	71	20	9
,, ,, 5 ,, 4.	68	23	9	11	78	11	26	32	42	65	30	5
Whole sound-area	73	18	9	24	64	12	12	46	42	74	20	6
Do. for Derby earthq. of 1903	57	37	7	...	...	...	21	55	24	46	46	9
,, ,, ,, 1904	65	29	6	30	62	8	18	51	31	62	31	7

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 14.

From this table it follows: (1) that, as in previous British earthquakes, there is no evidence of any difference in velocity of the sound-waves and of the waves containing the larger vibrations which form the sensible shock; and (2) that the sound before and after the shock was more prominent than usual, indicating that the marginal regions of the foci were of comparatively-large dimensions in a horizontal direction.

IV. Origin of the Earthquake.

The only known element of the fault in which the earthquake of 1902 originated is its average direction, which is E. 25° N. and W. 25° S. For the earthquake of 1905, little more can be determined. The line joining the centres of the two portions of the isoseismal 7 runs north-east and south-west, and the longer axis of the isoseismal 6 is directed E. 38° N. and W. 38° S. It is probable that the latter coincides the more nearly with the average direction of the originating fault. If the isoseismal lines are accurately drawn, we should infer that the fault hades towards the north-west within the south-western focus and towards the south-east within the north-eastern focus. The distances between the isoseismals 7 and 6 differ, however, by so small an amount that it seems to me more reasonable to conclude that the originating fault is nearly vertical in this portion of its course, though perhaps hading slightly to the south-east in the neighbourhood of the north-eastern focus. It could hardly be otherwise, if the earthquakes of 1902 and 1905 were connected with the same parent-fault.

Of the existence of this connection there is no direct proof; but its probability may be inferred for several reasons:—(1) both earthquakes occurred in a district seldom visited by such disturbances; (2) the north-eastern epicentre of the earthquake of 1905 is very close to the minor axis of the earthquake of 1902; and (3) the direction assigned to the originating fault in each case is nearly the same. The displacement which gave rise to the earthquake of 1902 would be more likely to lead up to a displacement along the same fault than to one in another fault of the same system.

With regard to the fore-shock in 1905, there is but little evidence; it may have originated in the interfocal region or in the north-western focus, but the displacement causing it was too small to have had much influence on the succeeding movements. The first of these occurred in the south-western focus, and rapidly extended across the interfocal region until another comparatively-large slip took place within the north-eastern focus. Of the two principal movements, the latter was slightly less pronounced than the former, possibly owing to relief of stress three years before. There is no evidence of any after-slip in the interfocal region; but this may have been rendered unnecessary by the movement that intervened between the two chief impulses.

A twin-earthquake, as I have endeavoured to show in a recent

paper,[1] is due to the differential growth of a crust-fold along a fault which intersects it transversely. As a general rule, the first movement is a rotation of the middle limb accompanied by the almost simultaneous slip of the two arches, and followed after an interval, which is usually brief, by a shift of the middle limb. The movements, in which the Doncaster earthquake originated, presented a slight variation in order. They consisted of successive, but continuous, displacements, first of the south-western arch, then of the middle limb, and finally of the north-eastern arch.

EXPLANATION OF PLATE II.

Map illustrating the area affected by the Doncaster earthquake of April 23rd, 1905, on the scale of 25 miles to the inch.

[1] 'Twin-Earthquakes' Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 18–33.


* Boundary of Area
the Second Part o
was the stronger.
Wigan
Liverpool
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MAP ILLUST

rating the Area affected by the Doncaster Earthquake of April 23rd, 1905.

3. *The* Glacial Period *in* Aberdeenshire *and the* Southern Border *of the* Moray Firth. By Thomas F. Jamieson, F.G.S. (Read November 8th, 1905.)

Contents.

I. Introductory.

That north-eastern angle of Scotland which lies between the Moray Firth and the Firth of Tay presents some special features of interest in connection with the history of the Glacial Period, inasmuch as it seems to have been less heavily covered with ice than the rest of Scotland. Nevertheless, no part of the area appears to have escaped invasion, for the ice which filled the basin of the Moray Firth extended over all the southern border of that basin, and even overflowed a considerable part of Aberdeenshire, spreading southward until it met those streams which, proceeding from the Grampian Mountains, moved eastward along the valleys of the Dee and the Don. No part of the surface, therefore, escaped abrasion by the ice; and no remnant of pre-Glacial Tertiary deposits has hitherto been found in any part of the area, even in those spots where one would have thought that they might have been most likely to be preserved. Neither has any trace been obtained of the mammalian fauna which inhabited England during the inter-Glacial Period. No remains of the Mammoth, not even a tooth or a tusk, have been met with in any of the railway-cuttings or other excavations (so far as I am aware), although such have been found in Ayrshire and in the Basin of the Forth.

II. The Red Clay of the Aberdeenshire Coast—its Origin and Derivation.

One of the most interesting features in the Glacial Geology of

Aberdeenshire is the Red Clay which occurs along the eastern coast of that county. Some account of it will be found in vol. xxxviii of this Journal (1882) p. 160, where I endeavoured to show that it had been formed during a time when there was a flow of ice along the coast from south to north, caused apparently by the approach of the Scandinavian Glacier, which had the effect of blocking the natural outlet of the Scottish ice to the east, and compelling it to turn along the coast nearly at right-angles to its natural course. This northward flow brought with it red sediment and multitudes of stones from the sandstone-rocks and associated volcanic beds of Forfar and Kincardine. A subsequent visit to that district enabled me to ascertain that the mineral character of the volcanic fragments which occur in this Aberdeenshire Clay, is identical with that of the rocks along the coast between Montrose and Lunan Bay. Here I may mention that so long ago as December 2nd, 1840, Sir Charles Lyell[1] remarked that the observations of Mr. Blackadder and himself led them to infer, that a great flow of glacier-ice had at one time gone along the Valley of Strathmore from Dunkeld north-eastward to the sea at Lunan Bay; a circumstance which harmonizes very well with the further transport from Lunan Bay northward along the coast to Aberdeen. If this diversion of the Scottish ice from its natural direction was caused by the approach of the Scandinavian Glacier, it enables us to connect the Glacial history of Scotland with that of the Norwegian ice when it attained its great spread to the west. I shall therefore give some further particulars regarding these Red-Clay beds, as new opportunities of studying them have arisen since I wrote my paper on the subject. A line of railway has been formed from Ellon to Cruden, right through the district where they are best developed, and in the cuttings of this line some interesting sections were brought to view. Large excavations have also been made near Peterhead, in connection with a convict-prison and a harbour of refuge; while near Aberdeen fresh diggings have been opened up in the clay-pits, as well as excavations for some deep sewers close beside them.

These red beds exhibit a great variety of character. Sometimes they consist of thick masses of pure clay, which is often finely laminated, a proof of tranquil deposition in water of some depth. Sometimes thick beds of fine sand and gravel are associated or interstratified with this clay. In other places the clay is of coarser quality, being mixed with stones, and showing no appearance of stratification; in which cases it often presents a hard firm texture, quite like a Boulder-Clay. All these varieties, however, pass occasionally into each other, as if they belonged to one and the same series. The character of the sections changes frequently and abruptly, sometimes within a few yards. The arrangement is not often in straight regular beds, but is generally undulating, often rapidly so. Finally, there are in some places esker-like mounds of gravel, such as those beside the Loch of Slains, which contain the

[1] Proc. Geol. Soc. vol. iii (1842) p. 342.

débris of Crag-shells and fragments of Secondary limestone. These mounds, I find, form part and parcel of this Red-Clay Series, for the Red Clay occurs both above and below them.

From the foregoing account it will be seen that this Red-Clay Series presents features somewhat resembling the Drift-deposits of Lancashire and Cheshire, and like them it occasionally contains sea-shells, generally more or less broken. In certain localities, as at Aberdeen and Peterhead, clay of a different colour is interstratified or mixed with the red, showing that there has been in such places a mingling of sediment from different sources.

The esker-like mounds of gravel occur along what seems to have been the western border of the mass of ice which came northward along the coast. These mounds may have been formed by streams of water tumbling from the margin of the glacier, and washing off the mineral débris embedded in or lying on the ice. The purer masses of clay seem to have resulted from clouds of muddy sediment subsiding in a sheet of water lying in front of the ice, between it and the land.

In connection with these Red-Clay beds one noteworthy circumstance is the evidence which they afford that, at the time when this northward flow took place along our coast, the Aberdeenshire ice was shrinking, or had already shrunk, much within its former limits. During the preceding period, when the subjacent grey Boulder-Clay was deposited, the Aberdeenshire ice came down to the coast, and even advanced beyond it; but, during the deposition of the Red Clay, this local ice had made a decided retreat, and the coastal district was under water. Specially was such the case in the Valley of the Dee. This river takes its rise among the mountains of Braemar, the highest group of hills in Britain, and flows along a well-defined valley terminating in the sea at Aberdeen. It might therefore be thought that here, if anywhere, we should have had a very large and persistent glacier. Nevertheless it is quite clear, that during the deposition of the Red Clay the Glacier of the Dee had receded some distance up the valley; for the Red Clay lies right across the mouth of the stream at Aberdeen, and wasted patches of it have been noted for about a couple of miles up the bed of the river. This shows that the Aberdeenshire ice must have been comparatively thin, so that it melted away long before the heavy ice which covered the Western Highlands and the valleys of Perthshire. There is nothing unintelligible in this, for the Tay and its main tributaries take their rise in the rainy district of the West, where the fall of snow during the Glacial Period seems to have been very heavy; whereas Aberdeenshire and its rivers lie on the drier side of the country, where the fall of snow was doubtless much less. Therefore, from meteorological considerations alone, we might expect the local ice there to have been much thinner. Consequently, the glacier that filled the Valley of the Dee would shrink long before the glacier which came down the Valley of the Tay, and along Strathmore to Lunan Bay.

In Strathspey, which has a comparatively slight rainfall, a similarly-early shrinkage took place, as we know from the phenomena of the Parallel Roads of Glen Roy, and other facts which I shall mention farther on. In proof of the state of matters at the mouth of the Dee, we have excellent evidence in the clay-pits at Aberdeen. These were formerly worked on both sides of the river, but of late only on the south side at Torry, where the clay has long been dug for the manufacture of drainpipes and bricks. I have visited the excavations at intervals for the last forty years or more, and am consequently well acquainted with the varying nature of the sections displayed there.

The river at Torry is bordered on the south side by a ridge about 150 feet high, which consists of granite and gneiss covered by Glacial Drift. The bed of fine clay, used for industrial purposes, occupies a sort of hollow nestling in the northern flank of this ridge, and thins out at an altitude of about 50 or 60 feet above the sea-level. It rests upon a grey Boulder-Clay which is rarely exposed to view, owing to the rise of water in the bottom of the pits. The lowermost portion lying immediately on the top of this Boulder-Clay is of a similar grey colour, and contains some irregular masses of sand and gravel of a like hue. The thickness of this grey portion, when best displayed, I found to be about 14 feet. This grey clay is delicately laminated by the interposition of films of mica between the leaves of clay. Above it comes a mass of red clay of a stiffer and more waxy nature than the grey, owing to the much smaller proportion of fine sand which it contains. This red clay at Torry attains in some places a depth of 14 feet, thinning out towards the ridge and thickening towards the river. Where it meets the subjacent grey clay, the two are generally interstratified for some distance. Above the red there is a few feet of grey clay, similar in colour to that which lies beneath, but of coarser texture and without appearance of lamination. This upper grey clay is often altogether absent, owing to the denudation which the top of the beds has undergone. A mass of ferruginous pebbly gravel of later origin, from 4 to 7 feet thick, lies upon the denuded top of the clay. The red and grey clays at the bottom are remarkably free from stones; often not a pebble of any kind is to be seen, but now and then a stone or two does occur, generally of no great size. No shells have ever been found in this Torry Clay, so far as I know. From the red clay I have, by washing and sifting, extracted one or two specimens of foraminifera, but they seem to be rare, and I did not meet with any ostracoda. In the grey clay I found no organisms of any kind.

These clays at Torry have all the appearance of having been deposited in very tranquil water, after the Glacier of the Dee had retreated some distance up the valley. The stillness of the water may have been caused by a thick covering of ice, which would account also for the absence of stones. The grey bottom-clay was probably formed from the fine mud proceeding from the end of the Dee Glacier, but the red clay marks the incoming of sediment from a

totally-different quarter, when the Glacier of the Dee had apparently retreated still farther back.

In the old clay-pit on the north side of the river opposite Torry, the section was very similar,[1] but the beds were deeper, the Red Clay being 17 feet thick. This pit is now closed, and those at Torry also.

The Red Clay and sand, however, attain their greatest development to the north of Aberdeen, in the neighbourhood of Ellon, and in the coast-parishes of Slains, Cruden, Peterhead, and St. Fergus, which lie to the north of the River Ythan. On the lands of Ardiffery, near the parish-church of Cruden, the depth reaches 100 or 150 feet, and may be even more. Here a large proportion of the mass consists of sand, much of it very fine-grained and free from stones; varying in colour from reddish to pale-grey. Other portions are coarser and more pebbly, with some small débris of yellow and grey limestone. Crumbs and dust of Crag-shells[2] can generally be detected where this limestone-débris occurs in the sand and gravel. Beds of Red Clay are met with in any part, both above and below the sand, while seams of the two are often interstratified.

The character of the surface here is very moundy—large swelling mounds, but these do not run in long narrow lines like eskers. The stratification in their interior is generally undulating and irregular. The sand and gravel looks as if it had been shot down in great heaps. Much of it is well washed and free from muddy sediment, and there is a marked absence of big stones and boulders in the interior of these sand-beds; but a few big stones seem to occur on the surface in all parts of the district. It seems to me that the explanation of this heavy mass of material being lodged here, may be that great streams of water flowed off from the glacier at this place, washing out the mud, sand, and mineral-débris embedded in the ice. Farther off from where the border of the glacier seems to have existed, we find the deposit to be more of a clayey nature, lying in flatter widespread sheets; whereas, along what had been the margin of the ice, the surface is moundy, the accumulations much deeper, and the stuff consists mostly of washed gravel and sand, sometimes of very pebbly gravel, with occasional masses of coarse mud or Boulder-Clay.

In one of the railway-cuttings at Port Errol, in the parish of Cruden, there was a bed of Red Clay from 30 to 40 feet thick, having much the same composition from top to bottom. It showed no distinct stratification or lamination, and contained some small stones dispersed through it.

At Belscamphie, which forms the north-western boundary of the pebbly gravel that contains the débris of Crag-shells (*loc. cit.*) and Secondary limestone, the section was as follows. At the bottom was a mass of Boulder-Clay of a very dark indigo colour, containing small fragments of crystalline schist and granite. This rests upon the schistose rocks of the district, which crop out a little farther on in the

[1] Quart. Journ. Geol. Soc. vol. xiv (1858) p. 510.
[2] *Ibid.* vol. xxxviii (1882) p. 145.

exposure. The Boulder-Clay has an irregular undulating surface, and varies in thickness, but is not more than a few feet deep where the bottom is exposed. Above it lay a bed of Red Clay, followed by a bed of fine clean-washed sand. Then, on the top of the sand, came the rough gravel containing pebbles of yellow limestone, sandstone, and crumbs of (Crag) shells. In some places this stuff reached nearly to the top of the cutting; in others it was covered by a few feet of Red Clay and gravel. The total depth of the section was about 16 feet. The chief interest lay in its showing that the pebbly gravel containing débris of Crag-shells forms a member of the Red Clay Series, and that the whole lies above a bed of Boulder-Clay of quite a different hue and character, containing not a vestige of the limestone, sandstone, or shelly débris. This section is near Pitlurg railway-station.

In some of the projecting parts of the coast the Red Clay is often quite like a Boulder-Clay, being very firm and unstratified, with small stones dispersed through it. This is well seen at present along Peterhead Bay. Close to the south side of the town the shore is formed of low rocks of red granite, which are covered by a mass of hard grey Boulder-Clay, 10 or 12 feet thick, containing stones of gneiss, quartz, and granite. The surface of the rock does not show marks of glaciation, so far as I could see. In passing along the Bay southward, the grey Boulder-Clay is very soon observed to become covered by a mass of Red Clay, which gradually attains a thickness of about 10 feet. It is nearly as hard and firm as the grey clay beneath, and contains a good many stones, some of which seem to have been derived from the Old-Red-Sandstone Conglomerate. It has all the appearance of a Boulder-Clay, such as would be found in a red-sandstone district. On advancing still farther along the Bay southward, one sees the granite gradually sink out of sight, and the grey Boulder-Clay thin nearly quite away into a mass of coarse granite-rubble. The Red Clay, on the other hand, grows thicker; and at Invernettie, about a mile south of Peterhead, where the bay curves more inland, the granite and its covering of grey Boulder-Clay have both sunk out of sight, but the Red Clay attains a much greater development.

The section is not now exposed as it was some years ago, when the tile-work was in full operation, but when best displayed I found it to be as follows. At the base was a mass of fine stratified sand, which seemed to descend below sea-level, but was not much exposed. On the top of this sand was a bed of fine laminated brown clay (what the workmen called leaf-clay), which varied in thickness from 1 to 4 feet. Above this was a mass of clay, attaining in some places a thickness of 15 feet, of a decided red colour; generally of fairly-pure quality, but showing no clear stratification, and having some stones dispersed through it. The top of this bed exhibited an undulating outline, and was covered by an irregular seam of coarser stuff from 6 inches to 3 feet thick, composed chiefly of small débris of gneiss and mica-schist. Above

this was a deep mass—20 feet thick or more—composed of darkish mottled brown clay, varying much in colour, as if a red and a blue had been jumbled together. It was quite unstratified, and contained more stones than the Red Clay beneath. These stones are of a great variety of kinds, and among them are some large ice-worn boulders, from 2 to 4 feet long. Above this came from 3 to 4 feet of coarse pebbly clay, of a more ferruginous tint, with a foot or so of arable soil at the surface. The total height of the bank is about 65 feet above the sea. The relative thickness of the beds varies in different places, but the section is now quite obscured by slips. In some places here the Red Clay is curiously streaked with clay of a dark bluish colour, derived apparently from a different source. In one spot, near the base of the section, I found a boulder of granite 2 feet in diameter, sticking in the fine sand and reaching partly up into the laminated clay above it. This stone was encased in a skin of bluish-grey gritty mud, 1 or 2 inches thick, quite different from the clay surrounding it, as if the stone had been covered with this mud when it dropped out of the ice, and fell down into the clay at the bottom of the water.

In the excavations for the convict-prison, which adjoins Invernettie on the south side, an irregular undulating band of blue clay was found in the midst of the red, accompanied occasionally by a bed of gravel, which contained a few broken shells. Many blocks of red sandstone were met with in the cuttings for the prison ; likewise a bit of hard Chalk, with a cylindrical fossil in it about the size and thickness of a cigarette (*? Belemnitella*), and stones of many different kinds. Among the broken shells, I observed *Cyprina islandica*, *Pecten islandicus*, *Astarte arctica*, *Panopæa*, *Mytilus*, *Cardium*, *Fusus*, and *Balanus*.[1]

I have noticed a similar bed of blue clay among the red near Cruden Bay. It is generally very undulating, of irregular thickness, and contains ice-scratched boulders. To the north of Peterhead, in the parish of St. Fergus, dark-blue clays are more developed, and are found embedded in the red, which shows that they belong to approximately the same period. North of St. Fergus the Red Clay disappears, and is replaced by clay of a dark indigo colour, sometimes nearly black. This dark clay extends along the coast westward, past Banff, on to Portsoy and Cullen, and indicates a transport from north-west or west.

Since writing my former paper on the Red Clay I have found a few more instances of glacial markings on the rocks along the coast of Cruden, running in a general direction from south to north, or parallel to the coast; but they were exceedingly slight and of no great extent. Those at Murdoch Head, pointing towards the Buchan-Ness Lighthouse, are still the best that I have been able to discover, and are unequivocal. The

[1] Further details regarding the clay-beds near Peterhead will be found in Quart. Journ. Geol. Soc. vol. xiv (1858) p. 518.

rock there, however, is being quarried away, so that ere long they may disappear. These markings are at the top of the cliff, and are covered by red Boulder-Clay, at an altitude of 100 feet above the sea.

The glaciation of the rocks along the coast of Slains, Cruden, and Peterhead seems to have been so slight as to be scarcely observable. Perhaps the ice was not very thick, or was buoyed up by the water which submerged the coast at that time, or it may have had little motion. The granite below the grey Boulder-Clay at Peterhead shows a like absence of glaciation. At the Government Quarry, on the west side of Stirling Hill, the rock, when newly uncovered, does show indications of abrasion by an agency coming from south or south-east, but I could find no undoubted scratches or scoring by the ice.

III. Relation of the Chalk-Flints to the Red Clay.

In the patches of Red Clay found sporadically on the top of Stirling Hill and the adjoining eminences, fragments are common of the crystalline schists, which form the rocky coast of Slains and Cruden lying to the south-east at a lower level. This shows that there had been an upward transport over the hill from that quarter during the time of the Red Clay. All this harmonizes with the general bearing of the evidence formerly detailed.

More interesting evidence, however, is derived from the distribution of the Chalk-flints which cover the ridge running inland from the sea at Buchan Ness. These flints lie generally thickest on the top of that ridge, but extend also down both sides of it. I find, however, that for about 2 miles inland from the coast they have been swept off, apparently by an agency moving across the ridge from south to north. The end of the ridge next the sea is called Stirling Hill, the adjoining summit to the west is called the Hill of Longhaven, and the next Coldwells. They are all composed of red granite, and rise to a height of about 300 feet above the sea, forming a continuous ridge: the last-mentioned portion attaining an altitude of 329 feet, which is the highest summit. All over the southern slope of these heights the flints are entirely absent, and on the top and eastern end of Stirling Hill the same is nearly the case. On the top of Longhaven Hill a stray flint or two may be found, and they become more numerous as we approach the northern brow of the ridge, but on descending the north side they immediately become plentiful; while, in the Den of Boddam, which is a little, narrow, winding ravine running along the north side of Longhaven Hill, they lie in vast profusion. The same is the case on the farm of Sandford Hill, on the north side of the Den. All over this space the flints lie thicker than I have seen them in any other part of Aberdeenshire, or, indeed, of Scotland, forming in some places large mounds known as the Saddle Hills.

Blocks of granite, some of them 4 to 6 feet long, lie on the top of the flints along the northern shoulder of the Longhaven ridge, as if

they had been swept down from above by the same agency as that which carried off the flints. At the granite-quarry on the west side of Stirling Hill, there is a like absence of flints on the crest of the ridge, but they are found plentifully in the hollow to the north of the quarry, where they are mixed with much coarse granitic sand, which seems to have been scoured off the rock by the passage of the ice. At the Hill of Coldwells, although there are no flints on the south side, these make their appearance as soon as we reach the top, where they are in many places quite plentiful. The bare granite crops out all over the summit of Longhaven and Stirling Hills, especially along the seaward front of the latter. At Coldwells, which lies farther inland and attains a somewhat greater height, the denudation has been less complete, and the rock is scarcely exposed.

Another proof of the northward movement of ice along the east side of Aberdeenshire may be mentioned. When the railway-cutting at New Machar Station was in progress, I observed that the edges of the nearly-vertical beds of gneiss were bent over at the surface from south or south-west to north or north-east, as if by the passage of ice coming from the southward. This station is about 9 miles north-north-west of Aberdeen. Esker-like mounds of gravel may be traced a little inland along the coast from Belhelvie northward, throughout the parish of Foveran, on to the village of Newburgh on the River Ythan. These mounds occasionally have some Red Clay on the top, and contain fragments derived from the red sandstones. They probably mark the border of the stream of ice which came along the coast from the south, during the time of the deposition of the Red Clay.

IV. Question of Submergence.

It is quite clear to me that this Red Clay has been brought to Aberdeenshire by a drift of ice from the south, at a time when the coast was submerged beneath water to a level exceeding 300 feet above the present coast-line. Whether this submergence was caused by a depression of the land beneath the present sea-level, or by a sheet of water hemmed in between the ice and the land, is not quite clear. The evidence afforded by the Red-Clay beds in Aberdeenshire is not conclusive on this point, for as yet they have failed to yield any instance of a bed of undisturbed sea-shells in what would seem to be their original habitat; although such instances do occur to the southward at Montrose, Errol, Elie, and probably some other localities. In Aberdeenshire, the few shells met with in the Red Clay are generally more or less broken, and may have been transported from a distance; it is true that a few whole ones have also been found.

V. Succession of Beds—an Older Boulder-Clay Discovered.

The whole of our Glacial Beds in Scotland are, no doubt, later than the Forest-Bed Series of the Norfolk coast, perhaps later even

than the Chalky Boulder-Clay of that region. In the Ellon district of Aberdeenshire the regular succession, beginning at the surface, is—(1) Upper Boulder-Clay and gravel; (2) the Red-Clay Series, consisting of clay, sand, and gravel; and (3) grey Boulder-Clay, which usually rests upon the old rocks of the district, and seems to have been lodged by a sheet of ice coming from about west-north-west.

Recently, however, I have found remains of a still older Boulder-Clay of a very distinct character. These instances occurred near Ellon railway-station, between the line of railway and a low rocky eminence called the Craigs of Auchterellon. This eminence consists of a mass of gneiss jutting out across the valley on the north side of the Ythan, and rising to a height of nearly 100 feet above that stream. Some wells have been sunk at the east side of these rocks, and it was in digging them that this older clay was discovered. After getting through the Red Clay and the underlying grey Boulder-Clay, a mass of very dark indigo-coloured clay was reached, of a finer quality, with fewer and smaller stones; but what was most remarkable, was the circumstance that it contained small fragments of sea-shells, generally mere crumbs, but some few of them in such condition as enabled me to recognize *Cyprina islandica*, *Astarte arctica*, and a bit of a *Balanus*. Moreover, some of them showed clear marks of glacial rubbing, like those met with in the Caithness Drift. Now, the grey Boulder-Clay here has never yielded any trace of shells or other organisms. It has always proved barren, with no remains of animal or vegetable life. This dark blackish clay is, therefore, evidently a distinct and older deposit, and its occurrence in this particular spot has no doubt been due to its lying on the east and lee side of the rocky eminence, which sheltered it from the demolishing action of the ice-stream that lodged the grey Boulder-Clay, whose flow was here from west to east.

Many other wells have been sunk at Ellon, but it is only in those close to the east side of the Craigs that this older black clay has been found; and it is thickest in those wells which are nearest to the east side of the rocks.

It is also the case that the Red Clay is thickest and best preserved on the east side of similar eminences, and for the very same reason: these having sheltered it, to some extent, from the denuding action of the later ice-sheet, which lodged the Upper Boulder-Clay and gravel. In the well nearest the Craigs the black clay was 20 feet thick, and then the bottom was not reached. In another, a little farther off, about the same thickness was got, but here the bottom was apparently touched. It was covered by 20 feet of the grey Boulder-Clay, above which came 6 feet of waxy Red Clay, and 6 inches of arable soil at the surface. In both wells the black clay contained remains of shells, and was of similar character.

The discovery of this old dark Boulder-Clay, so distinct in its features, and lying below the grey (which is the bed usually found next the rock in this quarter), brought to my recollection the fact

that I had noticed a somewhat similar dark clay in a like position in other places, but not showing any shell-fragments. Thus, in a railway-cutting a few miles south of Ellon, I had observed that the lowermost part of the section was composed of a very dark indigo-coloured clay, in which I found a piece of fossiliferous shale containing the impression of a small ammonite, and what seemed to be fish-scales.

The bottom-clay in the railway-cutting at Belscamphie, on the Cruden line, mentioned on p. 17, is also very like the dark bed at Craigs of Auchterellon. I found, however, nothing remarkable in it, although I did get a crumb or two of what might have been shell, which effervesced on being treated with acid. I could also mention other localities in this quarter, where a very dark bluish clay occurs beneath a Boulder-Clay of greyer hue.

I therefore think that there may have been a fairly-widespread dark clay of older date than the grey, and formed by a previous phase of the ice. The action of a thick sheet of glacier-ice moving over the surface of a country would be something like that exerted by a carpet dragged over a floor, and, if long-continued, would leave very little if any older loose stuff behind it. Its plastic nature and heavy pressure adapt it so closely to all irregularities of the floor on which it rests, that hardly any place can escape its friction; and this accounts for the entire absence of all remains of pre-Glacial Tertiary deposits in Scotland. Each recurrence of an ice-sheet would tend to wipe out the material left by its predecessor, especially if the later one was heavy and long-continued.

Although, then, we have some evidence of more than one recurrence of an ice-sheet in this part of Scotland, no evidence has hitherto been obtained of warm intervals, further than what may be inferred from the melting-away of the vast mass of ice which preceded and followed the deposition of the Red Clay and the shell-beds at Clava and elsewhere. It must have taken a great deal of heat to melt these enormous masses. The deposition of the Red Clay seems to have followed close upon the retreat of the ice which lodged the grey Boulder-Clay. There is no sign of any interval there; but a long interval, and possibly a warm one, may have occurred between the time of the Red Clay and that of the later ice-sheet which lodged the Upper Boulder-Clay and gravel.

The blackish shelly clay at Ellon must, I suspect, have come down the Ythan Valley from the Moray-Firth direction, and may be of the same age as the dark clay at Maud, to be afterwards mentioned (p. 29), which contains Oolitic fragments and pieces of serpulite-grit from the North-Western Highlands. These latter probably came down the valley of Loch Shin in the great ice-stream which seems to have descended along that route into the Moray Firth, and pressed on over the southern border of that basin. Their occurrence in the northern part of Aberdeenshire is a very curious and interesting fact, which we owe to the observation of Mr. John Milne, formerly tenant of the farm of Atherb.

VI. The Chalk-Flints of Aberdeenshire.

In regard to the beds of Chalk-flints which occur in Aberdeenshire, when I first saw them, more than forty years ago, I fancied that they might have been derived from a bed of Chalk that had formerly existed in the district. They are highly waterworn, and always accompanied by a quantity of quartz-pebbles which are likewise intensely waterworn. These I supposed might have been derived from the quartz-rocks that occur in the district. The flints and quartz-pebbles, however, extend for many miles along the top of a ridge of granite; and there I remarked that the granitic débris had none of this water-rolled character. The staurolite- and mica-schists (which form another part of the range of heights on which the flints lie) also show a similar absence of water-rolling. This feature, in short, is confined to the flints and the quartz-pebbles associated with them. It would, therefore, seem that both have been transported from a distance in company, and that the water-worn features had been impressed upon them before they were brought to the district where they now lie.

They do not occur on any part of the large spreading hill of Mormond in the northern extremity of Aberdeenshire, so far as my observation goes; but are mostly confined to a narrow belt of country running in a general east-and-west direction to the coast at Buchan Ness, a little to the south of the town of Peterhead. More than one phase of the Glacial Period has occurred since the flints were brought to Aberdeenshire, for this took place before the epoch of the Red Clay. They have accordingly been swept away, and re-arranged in many places by later developments of the ice and other denuding agents.

VII. Explanation of the Absence of Shell-Beds in the Red Clay.

The general absence of marine fossils in the Red Clay of Aberdeenshire may, perhaps, be accounted for in the following way. During the preceding stage of the Glacial Period, when the subjacent Boulder-Clay was laid down, the Scandinavian ice (as James Croll first pointed out) appears to have occupied the shallow bed of the North Sea and coalesced with the Scottish ice, so that the sea-water was excluded from all the East Coast of Scotland, and nothing but ice prevailed. Now, when the thaw began to set in, the thinner ice which lay over the eastern and northern parts of Aberdeenshire would no doubt melt first, and the water which took its place would be fresh or brackish, so long as free communication with the ocean was shut off by the Scandinavian Glacier. No migration of marine life into it would therefore be possible, until the latter glacier began to recede. It might have been a considerable time before that took place; consequently, the Red Clay would be deposited in a sheet of water hemmed in by the ice, and it would only be at a later stage that any marine forms of life would be able to gain admittance. This later stage is probably represented by the clay-

beds at Montrose, Errol, Elie, etc., where we find remains of Arctic mollusca and asteroidea, apparently in the place where the animals lived and died. The clay-beds at Aberdeen, as I have shown, afford good evidence that the glacier of the Dee Valley retreated, before the ice which came along the coast from the south gave way. Thus we actually have some facts in support of the explanation which I have suggested, while the absence of ordinary marine conditions presented by these beds seems to render some such explanation necessary.

VIII. The last Ice-Sheet.

Subsequent to the Red-Clay epoch, the inland ice again made a great advance, and apparently for the last time. The most satisfactory evidence of this in the Aberdeenshire district, is to be found at the seaward end of the Dee Valley and the coast immediately to the north of it. In this area there is clear proof, to one who is intimately acquainted with the ground, that the Dee Glacier came down to the coast with a breadth of at least 5 or 6 miles. In doing so, it destroyed the Red Clay along the greater part of that width, leaving some patches at the side of its track, but clearing it out completely along the central portion of its route.

The River Dee, at the lower end of its course, is bordered on the south by a continuous ridge of higher ground than it is on the north. The effect of this was to shunt the end of the glacier off to the north-east, so that, although the river now terminates at the city of Aberdeen, the central current of the ice-stream was diverted a mile or two farther north, crossing the present mouth of the River Don. This is well shown by the clear marks of the ice on the surface of the granite at the quarries of Cairnery and Persley, and also by the fact that the Red Clay has been wiped out most completely in that direction. Some patches have been left beside the present mouth of the Dee, as at Torry, Ruthrieston, and the Duthie Park.

The large mounds of coarse gravel and stones, on which much of the city of Aberdeen is built, are moraines of this stream of ice which came down the valley of the Dee. The Broadhill, the Castle-Hill (on which the barracks are built), Ferryhill, and many other eminences now covered with houses, are of this nature. In some of these mounds, masses of the Red Clay are to be found which have been dislodged by the ice and mixed with the moraine-gravel, as, for example, on the west side of the Broadhill. Some large ice-worn boulders occur in these mounds, generally near the top. One of these may be seen in the quadrangle of Marischal College, where it was placed a good many years ago, I believe by Prof. Nicol; but most of these big stones have been used up for building-purposes long ago.

The country around Aberdeen, before its reclamation, was so very rugged and encumbered with stones, that it is difficult now to realize its former appearance. Dr. James Anderson, who wrote a good sketch of the district in 1794 for the then Board of Agriculture, tells us that it was of the most barren nature that could anywhere

be seen; but that, about 50 years before the date of his report, a commencement had been made towards improving it. The expense of trenching and clearing the ground of stones and afterwards manuring it, often amounted to £50 or £60 an acre before a crop could be put in. Some fields, indeed, he says, cost £100 an acre. Yet, strange to say, the operation proved a profitable one. The demand for granite-stones to London about that time was so great as to help materially to make the enterprise pay.

On the lands of Nigg and Loirston, on the south side of the Dee, where the right flank of the glacier rested, the big stones cleared off the ground are so numerous that they have to be piled into what are locally termed consumption-dykes. These consist of two parallel stone-walls, 4 to 6 feet high, with a space of 10 to 12 feet between them, into which the stones are piled. These stones are of all sizes, up to 3 or 4 feet in length, and some larger. As an instance I may give the following: from 12 acres of land on the farm of North Loirston, the quantity of stones taken off formed a consumption-dyke (as I was told by the late Prof. Dickie) 300 yards long, 30 to 35 feet broad, and 6 feet high; in addition to which smaller stones were got to fill the furrow-drains, which were made 24 feet apart.

This last glacier of the Dee Valley must have protruded beyond the present coast-line. Its northern flank lay in the parish of Belhelvie, about 5 or 6 miles north of Aberdeen, where there is a great accumulation of gravel-mounds running inland, from a place on the coast called the Black Dog, to Parkhill in the parish of New Machar. These gravel-mounds rest upon the wasted top of the Red Clay at Milden and the Black Dog. At the latter place the clay is now dug for the manufacture of bricks and drainpipes. The right flank of the glacier lay on the hills of Nigg, which form the southern border of the Dee. In the intermediate space between Aberdeen and the Black Dog, the Red Clay has been swept clean away, causing a gap in it 4 or 5 miles wide.

Even in the little valley of the Ythan, there is evidence of Glacial action subsequent to the Red-Clay epoch. This valley is about half way between Aberdeen and Peterhead, and takes its rise among hills only a few hundred feet in height; consequently, it is difficult to believe that it could have originated anything like a true glacier. Perhaps the facts can be explained by the melting of deep masses of snow and ice, or it may be that a lobe or offshoot of the Moray-Firth ice came down this way. Anyhow, the Red Clay has been much wasted, and covered in places by masses of coarse gravel, and sometimes by a profusion of large stones 2 to 4 feet in length. At Michael Moor, a few miles to the west of Ellon, there is a sheet of this gravel in which the stones are so large and plentiful, that the agriculturist in clearing the ground has been obliged to form them into broad consumption-dykes, and farther up the river something like miniature lateral moraines occur. At Ellon, in some places big stones 3 to 4 feet long are found in great number, just at the bottom of the gravel and lodged on the top of the fine Red Clay.

In other parts of the country, the result of the last ice-sheet has generally been to form at the surface a thin covering of coarse mud, charged more or less with stones. In the lower coast-district this lies on the top of the Red Clay, and derives its colour partly from it; but, along the course of the rivers and minor streams, there is always more or less washed gravel, formed by the currents generated by the final melting of the snow and ice.

IX. The Crag-Shells and Chalk-Débris of the Red Clay—their Derivation.

The Crag-shells, and the débris of Secondary limestone accompanying them, which are found in some of the gravel-beds and clay of the Aberdeenshire coast, have evidently been brought thither by the ice-stream which produced the Red Clay, and may therefore have been transported from a very great distance. It has to be kept in view that pieces of chalk, sometimes iceworn and scratched, likewise occur in this Red Clay. They are met with at Montrose, Belhelvie, and also, though rarely, near Peterhead. Small pieces of coal have also been got in the same clay. The Cretaceous fragments have probably been brought to the east coast of Scotland by the Scandinavian ice, which passed over strata of Chalk in part of its route; and possibly the débris of the Crag may also have been brought by the same agency.

The bits of chalk are not uncommon in the Belhelvie clay and also at Montrose. It is not likely that they could have come from England, as the movement of ice to the south of the Firth of Forth was such as would have carried them in the opposite direction. Their occurrence at Montrose and Belhelvie tends to prove that this clay in Forfar and Aberdeen is all one and the same deposit.

The Southern Border of the Moray Firth.

In this district, the valleys have a general trend from south-west to north-east, as will be seen from a glance at any good map. The Ness, the Nairn, the Findhorn, the Spey, the Deveron, are the principal rivers, and they all flow in this direction. It might therefore be supposed that, during the Glacial Period, the ice would move down to the coast along these lines; but there is ample evidence to show that in some part of that period a great transport of boulders and mineral matter took place along the coast from west to east, right across the lower ends of these river-valleys, while marks left by the ice upon the rocky framework of the country, together with the drift of transported stones, prove that in some places the movement was from north-west to south-east.

X. Marks of Glaciation on the Rocks.

The finest display of this sort that I have seen in the district, is on the top of a low hill called the Carden Moor, not far from

Alves railway-station, about 6 miles west of Elgin. The late Dr. Gordon (of Birnie) took me to see it many years ago. The ridge lies east and west, and rises to a height of 250 or 300 feet above the level of the sea. The rock along the top is bare, and composed of a hard, fine-grained, grey sandstone of Devonian age, which has been strongly rubbed by the ice. The scratches and furrows point about 10° or 15° north of west, so that the line of movement crossed the ridge obliquely. Although the surface is unprotected by any covering of earth or clay, the markings are in many places as fresh and clear as if they had been made but a few years ago.

That the movement came from the west-north-west is shown by the transport of numerous fragments of the stone for many miles to the south-east.

On the sandstone of Quarrywood Hill, near the manse of New Spynie, Dr. Gordon showed me other instances pointing west 15° north, and on a hill near Burghead, west 30° to 35° north. The surface of the Cornstone beneath the Boulder-Clay at Linksfield Quarry, near Elgin, is also strongly glaciated, and even polished by the ice, the scores and scratches running from north-west to south-east. In one place, I found the direction almost due north and south.

Along the coast from Speymouth eastward to Fraserburgh, I have not met with any good display of glaciation on the rocks, but merely a few traces here and there, near Melrose Head, Crovie, Troup, and Aberdour. On the cliff at Troup Head I found some markings running east and west. At Kinnaird Head beside the town of Fraserburgh, the indications are more decided, showing a movement of ice coming from the north-west. The same direction is maintained round the corner of the coast to the fishing-village of St. Colms.

XI. Transport of Boulders—Jurassic Débris and Chalk-Flints.

The eastward movement of boulders along the southern shore of the Moray Firth has long been known to observers in that quarter.

At Linksfield[1] a huge mass of Oolitic beds, 40 feet thick and several hundred yards in length, has been transported bodily, and lodged on the top of the iceworn surface of a Devonian limestone, locally known as Cornstone, there being a layer of red Boulder-Clay 1 to 4 feet thick between the two. Other large transported masses of a similar nature have been found in the Elgin district at Lhanbryde, Spynie, and elsewhere.

At Plaidy, on the Turriff railway-line in Aberdeenshire, a great mass of greenish-blue Oolitic clay, brought probably by ice from the shores of the Moray Firth, has been stranded on the top of the slate-rocks of the district. It is so big that a tile-work has been established in it, and worked for many years. It was first discovered in making

[1] See the late Major L. Brickenden's account of it, Quart. Journ. Geol. Soc. vol. vii (1851) p. 289.

the railway in 1858. At that time I sent a notice of it to the Geological Society,[1] in which I termed it an outlier of Lias, but it is neither more nor less than a huge transported mass of clay, and is enveloped in Glacial Drift of a different colour. Judging from the character of the ammonites and other fossils which it contains plentifully, it has probably been derived from some bed belonging to the horizon of the Oxford Clay. It is much wasted on the outside, and partly mixed with the Glacial Drift surrounding it, but its full extent in some directions is hardly yet known.

Fossiliferous fragments from the Lias, the Oolite, and other Secondary rocks are found here and there over the country eastward, from Elgin and Speymouth across Banffshire, on to the coast of Aberdeen, beside Peterhead. Near Maud railway-station, in the north of Aberdeenshire, there is a small farm called Atherb. Mr. John Milne, the former tenant of that farm, is a man with the eye of a hawk for all manner of curious stones. He made a wonderful collection from the fields around it. Many of the pieces found by him are of a fine-grained grey sandstone containing Oolitic fossils: but what is still more interesting, he got several fragments of the Pipe-Rock, one of the characteristic Cambrian beds of the North-Western Highlands. I have myself found a small piece of shale, containing the impression of an ammonite and other fossils, embedded in the Boulder-Clay of a railway-cutting a mile or two south of Ellon, which is the farthest point in a south-easterly direction where such have been obtained.

Fragments of the Gamrie sandstone and conglomerate have been carried eastward along the coast towards Fraserburgh, and may be seen at various places along that line, and at the northern base of Mormond Hill.

The fossiliferous Greensand débris, which occurs at Moreseat in Aberdeenshire, proves to be also transported, probably from the north-west, and is embedded in Glacial Drift.[2] The Chalk-flints found so plentifully in that quarter have also, I suspect, been brought from the Moray Firth by the same glacial agency.

These flints, as I have said, are found chiefly along a belt of country running across the north of Aberdeenshire in an east-and-west direction, terminating at the coast near Peterhead, and may have been shed off along the southern border of one of the streams of ice which brought so great a quantity of other débris from the Moray Basin. They are generally most plentiful at the surface, except where covered by peat. Frequently they are mixed up with some gritty earth or glacial mud, or have some of it beneath them: but, at the western extremity of the district where they occur, they are covered in some places by Boulder-Clay of a later date, containing ice-scratched stones. This I observed near Delgaty many years ago, in 1858: it shows that there has been a recurrence of glaciation after the flints were laid down.

[1] Quart. Journ. Geol. Soc. vol. xv (1859) p. 131.

[2] See the Report of the Committee on Cretaceous Fossils in Aberdeenshire, Rep. Brit. Assoc. 1897 (Toronto) pp. 333 *et seqq.*

No chalk ever occurs with these flints, but there is occasionally some whitish earthy matter of a non-calcareous nature, consisting of silicate of alumina, derived no doubt from the weathering and waste of the flint-pebbles. This has sometimes been mistaken for chalk.

The north-eastern extremity of Aberdeenshire consists of low undulating ground, in the midst of which rises a large lumpy hill called Mormond, 769 feet high, composed of quartz-rock and staurolite-schist. At the western base of this hill is a low tract of coarse-grained grey granite. Blocks of this granite are scattered over the hill and far up it, to a height much exceeding that of the rock in place, while some of the smaller granitic débris is to be found on to the very top. There I also found stones of hard white quartz showing marks of strong glaciation, one of them being ground down to a smooth edge and streaked with fine scratches, showing that the abrasion had been most intense; but I found no flints on the hill.

XII. Extent and Depth of the Ice.[1]

All this seems to indicate pretty clearly that the ice had gone over the top of Mormond. From this hill westward to Inverness, at the head of the Moray Firth, is a distance of 80 miles in a straight line. If the glacier extended all the way, and was high enough to pass over the top of Mormond, as it seems to have done, it would be at least 800 feet thick along the coast opposite that point, and probably more. Then, if we allow an average slope of only half a degree, or 46 feet per mile, along the surface of the ice to Inverness, this would amount to 3680 feet on the 80 miles, to which add 800 feet for the height at Mormond, making 4480 feet for the altitude at the head of the Moray Firth. But the average surface-slope of the Greenland ice, where Nansen crossed it, is a good deal more than this, so that, in all probability, the height at Inverness was greater than I have stated.

XIII. Southern Border of the last Ice-Sheet where it crossed the Spey.

There is some interesting evidence to show at what point the southern edge of this great ice-stream crossed the Spey at the last time of its extension thither. Along that river, above Fochabers, the sandstone-rocks are of a deep red, and the Boulder-Clay derived from them is of the same hue. This red clay has been carried

[1] The ice-sheet which filled the basin of the Moray Firth was at one time so extensive that its right flank flowed round the northern parts of Banff and Aberdeenshire, while its left turned round over Caithness, originating the shelly Boulder-Clay of that quarter.

[Since this paper was written I have seen an article by Dr. W. Mackie, of Elgin, in Trans. Edin. Geol. Soc. vol. viii (1901) p. 91, on the distribution of erratics over Eastern Moray. It contains many interesting observations on the subject. At Ben Rinnes and some other places on the east side of the Spey to the south of Rothes, boulders are found which Dr. Mackie believes to have come across the valley from the west during some part of the Glacial Period, probably by the agency of land-ice.—T. F. J., *Nov. 25th, 1905.*]

eastward up the hollow traversed by the railway between Mulben and Keith. The rocks along this hollow are not of sandstone, but consist of quartz-rock and clay-slate, which give rise to Boulder-Clay of a grey colour, quite distinct from the red. These rocks are covered therefore by grey Drift, above which the red is sometimes visible. I traced this red clay as far on at least as Keith, so that the Moray ice must have moved eastward up this hollow.

At Rothes, a little farther south, and about 12 miles from the coast, we get to the outer edge of the red clay, which has been driven past the boundary of the sandstone. Here a hill called Ben Aigan, composed of quartz-rock and schist, 1500 feet high, flanks the Spey on the east. Lying against the northern base of this hill, there is a high bank bordering the stream and rising about 180 feet above it. This bank affords, or did afford many years ago, a most instructive section. The top consists of well-washed sand and gravel of a greyish colour, much of the sand being so fine as to be blown about by the wind. Beneath that is a great depth of fine stratified silt and sand, of a general greyish colour, in the midst of which, but well down, a mass of red Boulder-Clay makes its appearance, stretching horizontally through the silt from the north, and thinning out to the south in tongues and ribbons, which are more or less interstratified with the grey silt. Northward, that is to say down the river-side, the red pebbly mud grows rapidly thicker, and occupies the whole depth of the bank, which lowers abruptly owing to the termination of the grey silt in that direction.

We seem, therefore, to have here the very spot up to which the southern margin of the Moray ice had extended. It had apparently dammed the water and formed a deep pool or lake, in which the sand and mud coming down the flank of Ben Aigan and the Spey was quietly deposited. Here, as in the Valley of the Dee, the local glacier of the Spey appears to have shrunk back long before the thick ice coming from the West Highlands gave way. This harmonizes well with the evidence derived from the Parallel Roads of Glen Roy, which showed that the water of the glacier-lakes of Lochaber found an open way out by the Spey Valley when all the country to the west was still heavily clad with ice.

Terraces of gravel occur on both sides of the Spey at Rothes, at corresponding heights, the top of them being fully 400 feet above the sea. They also run up the Mulben hollow, where there are deep banks of Drift, in some of which I could distinguish a middle zone of red, with grey material both above and below. When the Moray ice-stream gradually shrank, it must have dammed the river at lower and lower levels. Accordingly we find remnants of gravel-terraces here and there, at decreasing heights as we proceed down the stream, at Cairnty and elsewhere. When I first examined these terraces 47 years ago, I thought that they had been caused by the sea,[1] but no marine fossils have ever been found in any of them. These terraces

[1] See Quart. Journ. Geol. Soc. vol. xiv (1858) p. 527.

probably date from near the close of the Glacial Period. At all events, they must be of later age (I should think) than the mollusca, the remains of which are got in the silt at Clava, to be mentioned in the sequel (pp. 33–34).

XIV. Period of Submergence—Shell-Beds.

We find that during a certain stage of the Glacial Period there was a marked retreat of the ice, and that water occupied the coastal district eastward from Inverness. In my paper on the Red Clay of Aberdeenshire, I adduced evidence to show that, from the mode of its deposition and the altitude to which it extends, the submergence in the district where that clay occurs must have exceeded 300 feet. As much of the country stretching round the corner of Aberdeenshire to the Moray Firth lies below this level, a submergence of that amount would extend into both districts.

The question now arises, What was the nature of that submergence? Was it caused by a depression of the coast below the sea, or was the district covered merely by a sheet of fresh water enclosed between the ice and the land? In the Red Clay itself, although we occasionally find a few scanty remains of sea-shells, these on the whole are rare, and generally more or less broken. No bed of them has been found in place. At Annochie, however, on the coast a little to the south of Rattray Head, where a tile-work formerly existed, there is a bed of fine dark-blue silt, passing underneath the beach and extending some distance inland, in which I found Arctic shells having all the appearance of being embedded in their native mud. Although the position is close to the present level of the sea, the assemblage of species is decidedly a deep-water one, and indicates a very considerable amount of submergence. The prevailing forms were *Nucula tenuis* and *Leda pygmæa*, both occurring in a perfect state, with the olive-coloured epidermis quite unruffled. There were also specimens of the large Arctic form of *Saxicava arctica*, a *Cylichna* which appears to be the *C. alba* of Brown, likewise the little *Bulla turrita* of Möller (otherwise known as *Utriculus pertenuis* of Gould, var. *turritus*), and one or two small shells belonging to the genus *Axinus* (otherwise termed *Lucina* or *Cryptodon*). One of these seemed to be *A. ferruginosus*. Another was thought by the late Dr. Torell to be the *Axinus Sarsii* of Philippi. All these species are Arctic, and go down into very deep water, as will be seen from the following table giving the range of depth according to G. O. Sars, in his 'Mollusca Regionis Arcticæ Norvegiæ' Christiania, 1878:—

	Fathoms.
Nucula tenuis	20 to 300
Leda pygmæa	20 ,, 650
Saxicava arctica	0 ,, 300
Cylichna alba	10 ,, 300
Bulla turrita........	10 ,, 60
Axinus ferruginosus....	40 ,, 300
Axinus Sarsii	60 ,, 300

Also a large specimen of *Cornuspira foliacea* and other foraminifera.

There was a complete absence, not only of littoral species, but even of those characteristic of shallow water, and likewise of broken shells. Owing to the decay of the shelly matter it was difficult to extract specimens satisfactorily.

At King Edward, about 6 miles south-south-east of Banff, a considerable number of Arctic shells (some 30 species or more) have been found in the banks of a small stream which is a tributary of the Deveron. These have been collected by Dr. Milne of that locality, Dr. John Horne, F.R.S., and myself. Most of them occur in confused beds of sand, gravel, and pebbly clay. The most abundant are *Tellina balthica*, *Bela turricula*, *Natica grœnlandica*, and *N. islandica*. Many of the univalves are entire, but the others occur only as single valves or broken fragments. A similar group of shells occurs in a bed of fine sand, on the Banffshire coast at Gamrie, and at a similar height above the sea. Lists will be found at the end of my paper on the 'Last Geological Changes in Scotland.'[1] In one spot, however, of the King Edward banks, I found Arctic shells embedded in a fine bluish silt, apparently where the organisms had lived and died. The prevailing species was the *Tellina proxima* of Brown (*T. calcarea* of Chemnitz). The specimens were of large size, with the two valves in conjunction and shut, part of the dark-brown epidermis still remaining on them. The valves were, however, more or less cracked, the upper one sometimes quite squashed, as if caused by pressure from above; but the fragments were not shifted out of their place. Streaks, too, of carbonaceous matter were observed near the shells, as if derived from the decayed seaweed. *Leda pernula* and a *Natica* likewise occurred, both still retaining the epidermis, but they were much rarer than the *Tellina*. The silt also yielded foraminifera and ostracoda. This bed of bluish silt is about 160 feet above the present sea-level, and 5 miles south of the coast of the Moray Firth.

It must be borne in mind that, subsequent to this period of submergence, there was a recurrence of very intense Glacial conditions, as I endeavoured to show in my paper on the last stage of the Glacial Period in Scotland.[2] This return of the great ice-sheets broke up and destroyed the shell-beds, burying some of them under heavy masses of Boulder-Clay, as we see at Clava, in Cantyre, in the south of Arran, and in the later discoveries by Mr. Smith in Ayrshire, as well as in this case at King Edward. At Clava, 6 miles east of Inverness, the shell-bed is at an altitude of no less than 500 feet. There the group of species indicates shallow water, the commonest kind being the *Littorina litorea*. The locality was carefully investigated by a committee of the British Association in 1892, with the result that Mr. Fraser, the original discoverer, Dr. John Horne, the late Dr. David Robertson, and myself, all inclined to the belief that the shells were really in place, and indicated a submergence exceeding 500 feet.

[1] Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 197 *et seqq.*
[2] *Ibid.* vol. xxx (1874) p. 317.

This Clava bed is covered by a great thick sheet of Boulder-Clay, showing that intense Glacial conditions must have supervened after the shells were laid down; but the occurrence of marine mollusca there shows that at the time when they lived, the mass of ice which formerly filled the basin of the Moray Firth must have melted away as far at least as Inverness, at the head of the Firth. This is further proved by a remnant of shelly silt which I observed at Ardersier, near Fort George, 10 miles north-east of Inverness. The prevailing shell in it was *Astarte sulcata*, but I found also *Leda pernula*, and a specimen of *Tellina* which seemed to be *T. proxima* of Brown. The shells had been entire and showed the epidermis, but were much crushed and decayed, so that it was scarcely possible to get them out in a state suitable for examination. The silt containing them was very hard, as if it had been heavily pressed, and was unconformably enveloped by a mass of unfossiliferous Drift of quite a different colour and character.

XV. The Dark-Blue Clay of the Banffshire Coast and Northern Aberdeenshire.

The clay-beds found along the northern coast of Aberdeen and Banff are generally of a dark bluish tint, often nearly black when wet. This colour of clay extends from Fraserburgh sporadically all the way west to Cullen, near where is a bed of it at Tochineal, which has been worked for tiles for many years. A little to the east of Portsoy, I noticed remains of Arctic shells scantily dispersed in this dark clay along the high banks facing the sea. These shells were in a more or less broken state. The only species that I could make out were *Tellina proxima*, *T. solidula*, *Astarte borealis*, and *Leda pernula*. The mass of clay resting upon the rock was about 30 feet thick, mostly all of a dark indigo tint, without appearance of stratification. Near the top it was browner in colour, with more stones and even some big boulders, but no shells.

This dark indigo-coloured clay often contains Jurassic fossils, which may have been derived from strata existing somewhere in the basin of the Moray Firth; and at Moreseat, in Aberdeenshire, débris of the Greensand occurs in a dark friable clay, possibly of the same age. This dark clay, however, does not seem to be the product of the last ice-sheet, for it is covered at Moreseat and elsewhere by a later Drift of a brownish or reddish tint.

On the estate of Cairnfield, to the south of Buckie, Mr. T. D. Wallace (of Inverness) noticed that the dark bluish-black clay was covered by red Boulder-Clay; and Mr. Martin (of Elgin) mentions that, on the eastern slope of Coulert Hill, near Lossiemouth, red Boulder-Clay wraps round a bed of fine blue clay containing belemnites and other Oolitic fossils. Mr. John Milne at Atherb also remarked that the ice-sheet which brought the blue fossiliferous clay must have come first, as it is always lowest, the red or yellow clay when present lying above it: such, indeed, is the case near Brucklay Castle.

At Turriff, 10 miles south-east of Banff, there is a mass of dark blackish-blue clay on the south-eastern brow of an eminence about 330 feet high, known as the Market-Hill. It has been dug for the manufacture of bricks and drainpipes, is a pure solid clay devoid of stones, and shows no distinct stratification or lamination. At the time of my visit, I found it to be 13 feet thick at the deepest place, and was told by the manager of the works that it passes down into a dark bluish silt or sandier clay. It has an irregular surface, as if it had suffered denudation, and was covered by a few feet of gravelly earth of a lighter brownish colour. It is not seen on the western slope of the hill. No shells or fossils had been found in it. There is a tract of low ground running from the eastern coast of Aberdeenshire up the Ythan Valley to Turriff, and then down the Deveron Valley to the coast at Banff. The summit-level of this hollow between the Ythan and the Deveron, where it is very narrow, is only about 180 feet above the sea, or perhaps a trifle less, wherefore a submergence of 200 feet would connect the basin of the Moray Firth with the sea on the eastern coast of Aberdeenshire by a channel of water crossing the country in a curving line from south-east to north-west. The Moray-Firth ice, when at its maximum, probably sent a lobe down this way, but during the period of submergence it would be occupied by water.

The shells at Gamrie, on the Banffshire coast, occur in a deep mass of fine sand containing seams of fine dark clay, forming a large mound rising to a height of nearly 300 feet above the sea, and resting upon a cliff of sandstone-rock about 80 feet high facing the bay. In the course of two visits I collected nearly thirty species of shells. They seemed to be confined pretty much to one seam in the sand, but as there is a want of sections in the upper part of the deposit, they may very likely occur there also. The group, as a whole, closely resembles that found at King Edward. The commonest were *Astarte borealis*, *Cyprina islandica*, *Tellina proxima*, *Tellina balthica*, *Cardium grœnlandicum*, *Bela turricula*, and *Natica grœnlandica*. The shells are very tender and much decayed, consequently they are apt to go to pieces, especially the larger bivalves; but many of the smaller valves and the univalves are entire. In some places there is a good deal of shelly débris in the sand. The specimens of *Tellina proxima* are numerous, some few of them with the valves connected by the ligament and shut. These were filled with sand. Size generally large; many of the valves measured $1\frac{1}{4}$ to $1\frac{1}{2}$ inches in length. The *Astarte* was of all sizes down to very young specimens, and in detached valves, the larger ones in fragments. The *Cyprina* was of various sizes, always in fragments. *Bela* and *Natica* were often entire. All the shells had lost their epidermis. Fragments of *Balanus* also occurred, some foraminifera, and the otolith of a fish.

The nature of the section I found to be as follows, commencing at the bottom :—

		Feet.
1.	Red sandstone-rock, rising up from the beach to a height of about	80
2.	Fragments of clay-slate and grit, partly waterworn, and mixed with small earthy débris of the same	4
3.	Compact, very firm, fine blackish clay, containing a few small stones, some of which are glacially striated; also a few crumbs of shells too small for identification. There are likewise subordinate seams of brownish sand in this clay	8
4.	A thin seam of waterworn pebbles of clay-slate and grit.	$0\frac{1}{2}$
5.	A thick bed of fine brownish sand	about 15
6.	A bed of blackish fine clay, similar to No. 3	5
7.	A bed of fine brownish sand, in some places full of shelly débris	2
8.	A bed of fine blackish clay, thinning out into sand.	

Above this there were no good sections, but merely small openings in places, mostly showing fine sand. No Boulder-Clay appeared. The seams of clay vary much in thickness when followed laterally. As a whole, the mass of this mound has the appearance of being deposited in water, and may have been a portion of the sea-bed during the period of submergence. Many of the shells have been pierced by boring mollusks, as at King Edward.

The King-Edward locality, however, seems to me one of more especial interest, inasmuch as it appears to afford good evidence of the demolition of marine strata by the subsequent action of glacier-ice; for I found there the fine dark silt containing complete specimens of *Tellina proxima*, passing up into a sandier seam containing a greater abundance and variety of shells, among which *Tellina balthica* was one of the most plentiful. Above this lay a heavy mass of unstratified pebbly clay with ice-scratched stones, and in the lower part shell-fragments. This Boulder-Clay of King Edward is of a dark-grey colour, varies in depth from 9 or 10 to 30 feet or more, and along the valley is covered by a mass of waterworn gravel 10 to 20 feet thick. In one place I found the Boulder-Clay passing down at the bottom into a bed of fine silt, with the stratification much deranged, and containing seams of gravel, broken shells, and shelly mud. The ice-scratches on the stones as they lay in this Boulder-Clay seemed as a rule to point west 5° to 40° north, which may afford some indication of the line along which the ice moved. Here, therefore, we seem to have caught the ice in the very act of smashing up the marine strata, and converting them into a shelly Boulder-Clay like that of Caithness.

At a place called Blackpots, on the coast 2 miles west of Banff, I examined an interesting exposure of the clay at the tile-work there. The top of the section rises to about 80 or 90 feet above sea-level, and the depth of material lying on the rock amounts to 60 or 70 feet. The greater part of the bank at the time of my visit was seen to consist of a fine, very dark, blackish-blue clay of a soft silty nature, which graduated laterally in the space of 20 yards into fine sand at one side of the section. This sand contains some

thin seams of gravel and small pebbles, in which I observed many small crumbs of shell. A few bits of shell occur also at times in the clay, and here and there a small pebble. The top of the section showed a bed of somewhat different nature, about 10 feet deep, consisting of a coarser earthy and pebbly brownish clay. I saw a good many stones of various kinds and sizes lying in the pit, which the workmen told me came out of this coarse clay at the top. There were three big boulders of greenstone or syenite, one of them 5 feet in length, ice-worn and scratched; several small pieces of grit or quartz-rock; and several of Jurassic shale, some of them ice-worn and containing ammonites. Bits of belemnites were likewise to be seen, and pieces of red laminated sandstone, also granite of different kinds. The base of the fine clay and sand was not exposed, and probably some Boulder-Clay may lie between it and the rock.

This black clay, as I have before mentioned, occurs here and there all along the coast-district from Fraserburgh westward to Banff, Portsoy, and Cullen; but, between Cullen and Inverness, the material covering the rocks is of a more varied nature, and generally lighter in hue. What has imparted this very dark tint to the Banffshire Clay is not very evident. Perhaps it may have been the waste of the slaty rocks and serpentine of that district, or of some Jurassic beds in the basin of the Moray Firth. This clay has evidently suffered much denudation since it was originally laid down, for in some of the little valleys that run inland from the coast I observed patches of it here and there along their sides, as in the Tore Glen near Troup Head; and in a gully at Northfield, in the same neighbourhood, I noticed wasted masses of it enveloped in a coarse Drift of browner hue. In a railway-cutting at the south side of Fraserburgh, I also observed that this fine black clay was covered by a few feet of brown clay of a coarser nature, containing ice-worn stones.

The dark clay may be traced right across the northern extremity of Aberdeenshire, where it ranges on to Peterhead, becoming gradually less black and more of a leaden-grey where it meets and mingles with the red. Along the top of the high cliffs from Banff eastward to Troup Head, there is little cover of any sort on the rocks, but at Melrose Head I obtained the following section, beginning at the surface:—

	Feet.
1. Coarse pebbly clay of a brownish colour	3
2. Ferruginous laminated clay, without stones	4
3. Fine black clay, like that of Blackpots, with few stones, but some of them ice-marked	1
4. Brownish débris of an earthy character, with some ice-worn stones	3
5. Débris of slate-rock, often ice-marked	2
6. Slaty rock, forming the cliff beneath.	

At Mill of Rathen, 4 miles south of Fraserburgh, a deep bed of bluish clay occurs, covered by a few feet of gravel. Fragments of *Balanus* and shells are found in this clay. The fine dark clay of the Banffshire

coast seems to have been formed under conditions very similar to those under which the Red Clay of Aberdeenshire was laid down. It also ranges up to a similar or even greater height, being found occasionally at fully 300 feet above the present sea-level. Like the Red Clay, it often passes into, or is interlaminated with, beds of fine sand.

Seeing that this dark-blue clay mingles with the red in the district where they meet, near Peterhead, there is every reason to believe that both belong to the same stage of the Glacial Period. Both have evidently been deposited under water, at least the finer-grained stoneless varieties. Both have undergone much denudation, and are frequently covered by coarser material containing ice-scratched stones. The dark-blue clay is the repository of the Jurassic débris, which seems to have been derived from the waste of strata in the Moray-Firth basin; while the Red Clay of Aberdeenshire is the repository of material from the Old Red Sandstone of Kincardine and Forfar, with its associated volcanic beds. It is in the Red Clay that we also find the curious débris of Crag-shells and yellow Secondary limestone, the source of which is difficult to conjecture.

The water under which these clay-beds were deposited must have extended all round the coast from Aberdeen by Peterhead, Fraserburgh, and Banff, to the Moray Firth, seeing that they can be traced along the whole of that distance to near Inverness. If their deposition followed close upon the decay of the preceding cover of land-ice, we may suppose that they would form first where the ice was thinnest, and where consequently it would melt away soonest. This would probably be at the angle of the coast near Fraserburgh, while latest of all would be the clay-beds near Inverness (such as that at Clava), and those to the south of Aberdeen where the Red Clay came from.

The remains of the shell-beds at Clava and Ardersier show that, at the time of their deposition, the sea-water must have occupied the head of the Moray Firth; and when such was the case, deposits of marine silt must have been formed all along its shores. What has become of them all? No other instances are known along the head of the Firth, except the two that I have mentioned; and it was by a mere lucky accident that the Clava one was discovered, Mr. Fraser having heard from some farmers that shells had been noticed in a clay-pit there, which led him to make a search. The recurrence of intense Glacial conditions, which is proved by the heavy bed of Boulder-Clay covering the shelly silt at Clava, affords an explanation of the destruction that has overtaken these marine beds. Although no other instances of their occurrence are known between Inverness and the mouth of the Spey, yet farther eastward, between Cullen and Fraserburgh, remains of Arctic shells are not so extremely rare. Now, this harmonizes with the belief that it was the recurrence of Glacial conditions which caused the destruction, for the ice would be heaviest and most destructive at the head of the Firth whence the flow proceeded.

The preservation of the mass of stratified sand and silt at Gamrie,

in which the shells are found, was probably due to its sheltered position in the lee of the great rocky cliff of Gamrie Head.

The amount of submergence at Clava must have been decidedly over 500 feet, which is greater than any of which we have evidence along the coast farther east. If the submergence was due to a depression of the land caused by the weight of ice laid upon it, then the depression should have been greatest where the ice was heaviest, namely, at the head of the Firth just where Clava is situated, and where, as I have mentioned, the depth of ice may have probably approximated to 5000 feet, or even more.

Discussion.

The President remarked that it would be strange indeed if a cordial welcome had not been accorded to a paper by one who had been a Fellow of the Society for nearly half a century, whose papers on Glacial geology had been frequently published by this Society—papers which, although theoretical questions were by no means avoided in them, were specially characterized by the great number and importance of carefully-recorded facts.

Prof. P. F. Kendall observed that the Author, whose name was one of the most revered in Glacial geology, had added a new division to the Glacial Series of the district with which he dealt, in the shape of the dark clay with the deep-water Arctic fauna. It was very similar to a transported mass of Drift which he had seen and described in the Isle of Man. Two problems still confronted the geologist in that district; one was the mode of deposition of the Glacial deposits, the other raised the question of the land-levels in that particular area during the Glacial Period. The distribution of the erratics, the striations, and the contents of the deposits seemed to group themselves in a remarkable manner. The direction of the striations was entirely corroborative of the lithological features: thus, the grey clay containing crystalline rocks derived from the interior of the country was striated from the south-west, while the other from the Old-Red-Sandstone area was striated from nearly due south. In the Inverness district, on the other hand, there appeared to be a low-level system of deposits associated with striæ from a south-westerly or north-westerly direction, while the high grounds south of Clava bore striations running from due south. These two results seemed, at first sight, to be contradictory, and it would be most interesting to ascertain the mutual relations of the two parallel sets of striæ. The time had now arrived when it became necessary for glacialists to group their facts with a freer hand, and to deal with larger stretches of Drift-country. The available evidence rather pointed to the influence of the Scandinavian ice-sheet, than to the wane of the Highland Glacier and the waxing of the Tay Glacier. As to the Clava shelly deposit, the speaker at one time concurred with the late Dugald Bell in declining to regard it as a marine deposit *in situ*. He subsequently abandoned that view, but it might be necessary, with this new evidence, to return to his former opinion.

4. *The* Geological Structure *of the* Sgùrr *of* Eigg. By Alfred Harker, M.A., F.R.S., F.G.S. (Read December 6th, 1905.)

[Plates III & IV.]

Contents.

I. Introduction.

The Tertiary igneous rocks of the Inner Hebrides have from time to time engaged the attention of many eminent geologists; and the results of their labours, interpreted by their skill and insight, have become part of the common stock of British geology. In certain cases the investigation has been conducted on an extended scale. This is true more especially of the work of Macculloch in the earlier days, and of Sir Archibald Geikie and Prof. Judd among those who are still with us. Nevertheless, it is only recently that any considerable part of that large and complex area has been mapped with the close attention to detail requisite in a complete geological survey. Even apart from the time demanded by such a minute examination of the ground, the large-scale Ordnance maps which make it possible have been issued only within the last few decades. Thus, in the ten years which the present writer has spent on this work, it has been his good fortune to enjoy facilities denied to his predecessors, besides benefiting by the fruits of their labours in the same field. Fortified by these advantages, he has been enabled to pass with less diffidence from observation to inference, even when the latter is at variance with the views of geologists of much wider experience. For, as might be anticipated, the results of the detailed survey, while generally confirming the conclusions of the recognized authorities, have sometimes extended, restricted, or modified them, or have even led to a decided difference of opinion.

The individual questions on which such difference of opinion arises are not many, but some of them have far-reaching consequences. They are, in all cases, questions the settlement of which demands both close examination of the ground and comparison of different parts of the region; and this is doubtless the reason why they have not been raised, at least in any very definite form, until the present time.

The most important modification of hitherto received opinion in consequence of the results of the survey, is the recognition of the intrusive nature of a large part of the rocks which have been generally regarded as extruded lavas. The rocks in question include fully half of those which build up the 'basalt-plateaux' constituting the greater part of the Inner Hebrides. As illustrating

the kind of evidence that is relied on, and as having also a direct bearing on the main subject of this communication, a summary discussion will not be out of place. Part of the evidence in the case of the Isle of Skye has already been set forth elsewhere,[1] and the conclusion there arrived at has been even more firmly established in the survey of the 'Small Isles' to the south.

The basalt-plateaux are made up of a monotonous succession of sheets of basic rocks, individually from 2 or 3 to 100 feet thick, and reaching an aggregate thickness of sometimes 2000 or even 3000 feet. The rocks composing these sheets are, broadly, of two kinds, which may be distinguished as basalts and dolerites.

The basalts are usually amygdaloidal, and more or less affected by secondary changes. They are comparatively soft and crumbling under exposure to atmospheric weathering, and are very largely concealed under superficial accumulations of Drift and peat. They are of fine texture, and have typically the microstructure which has been styled granulitic.

The dolerites are much fresher rocks, and much more durable, forming all the strong features in the plateau-type of landscape. Their escarpments show marked vertical jointing, sometimes assuming a very regular columnar habit. The rocks, excepting only the thinnest sheets, are of decidedly coarser texture than the basalts, and their microstructure is typically ophitic. These dolerites are, in aggregate thickness, at least equal to the basalts with which they alternate; and their salient outcrop gives them an appearance of very decided preponderance.

Such is the constitution of all the north-western half of Skye, of Eigg in general (excluding the upper part of the Sgùrr), of Canna, Sanday, and Muck, and of the greater part of Mull. My observations go to prove that, while the basalts represent superficial outpourings of lava at an early stage of igneous activity, the intercalated sheets of dolerite are intrusive sills belonging to a later date.

The dolerite-sheets run with remarkable regularity for very long distances, but occasionally they may be observed to shift their horizon among the basalts, to come together, or to separate. When they encounter a mass of coarse volcanic agglomerate, they often behave much more irregularly, being sharply diverted or abruptly terminated. They sometimes enclose abundant fragments of the amygdaloidal basalts, and in a few instances it has been verified that a sheet of dolerite cuts through a dyke of earlier date. These are more or less conclusive proofs of intrusion for the individual sheets which afford such direct evidence; but the cases in which some of these tests can be applied are, naturally, not very frequent. Much more convincing evidence is furnished by a comparative survey of the areas in which the rocks are developed.

In the first place, it is to be remarked that sheets of dolerite in all respects identical with those in question occur, not only among

[1] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, chap. xiv.

the basalts, but also among the subjacent Jurassic strata along the eastern coast of Skye and in the northern part of Eigg. Here their intrusive nature has long been recognized. It seems an arbitrary interpretation to make the dolerites intrusive when they occur below the base of the basalt-group, and extrusive when they occur above that line.[1]

More striking evidence is afforded by the volcanic agglomerates which are found in the basalt-group, mostly near its base but also at higher horizons. The fragments in these agglomerates are of basalt, sometimes with an admixture of sandstones and other rocks of extraneous origin ; but I have sought in vain for any undoubted fragment of dolerite similar to that forming the strong sheets in the neighbourhood. The same remark applies to the fluviatile conglomerates intercalated at various horizons in the basalt-group in Skye, Canna, Rum, and Mull. Since the dolerites play at least an equal part with the basalts in the succession as now seen, and are moreover of much more durable nature, the absence of fragments of the dolerites from these accumulations points to the conclusion that they were not there when the latter were formed ; or, in other words, that they are intrusive sills of later date.

Equally noteworthy is the horizontal distribution of the dolerite-sheets, as brought out by the mapping of Skye. The plutonic intrusions—peridotites, gabbros, and granites—which make the central mountain-tract of this island are surrounded by a belt of metamorphism, in which the basaltic lavas have a hard and tough consistency, with an absence of bedding, markedly in contrast with their usual characters. As the dolerite-sheets are traced from the plateau-country towards the mountains, they are found to die out, and they all terminate without entering the belt of hard massive basalt of the mountain-border. Further, in the mountains themselves, the gabbro and granite enclose many patches of basalt in a more or less metamorphosed state, some as much as a mile in length ; but the dolerite-sheets never form part of these enclosed patches.

Having regard to all these facts, the proof seems to be complete, not only that the dolerites are intrusive in the basalts, but that there is a great difference in age between the two groups, the basalts being older than the plutonic intrusions and the dolerites younger. Many other facts might be cited as confirming, directly or indirectly, these conclusions. The general sequence of the Tertiary igneous rocks established in Skye is found to be borne out in the other islands, and in particular the recognition of three successive phases of igneous activity in this region. These three phases are characterized respectively by (i) volcanic extrusions, (ii) plutonic intrusions, (iii) minor intrusions of hypabyssal habit; and the first event of the third phase is represented by the great group of dolerite-sills.

[1] Sir Archibald Geikie long ago recognized the intercalation of intrusive sills among the basalts, but he allowed them no importance except at the base of the series.

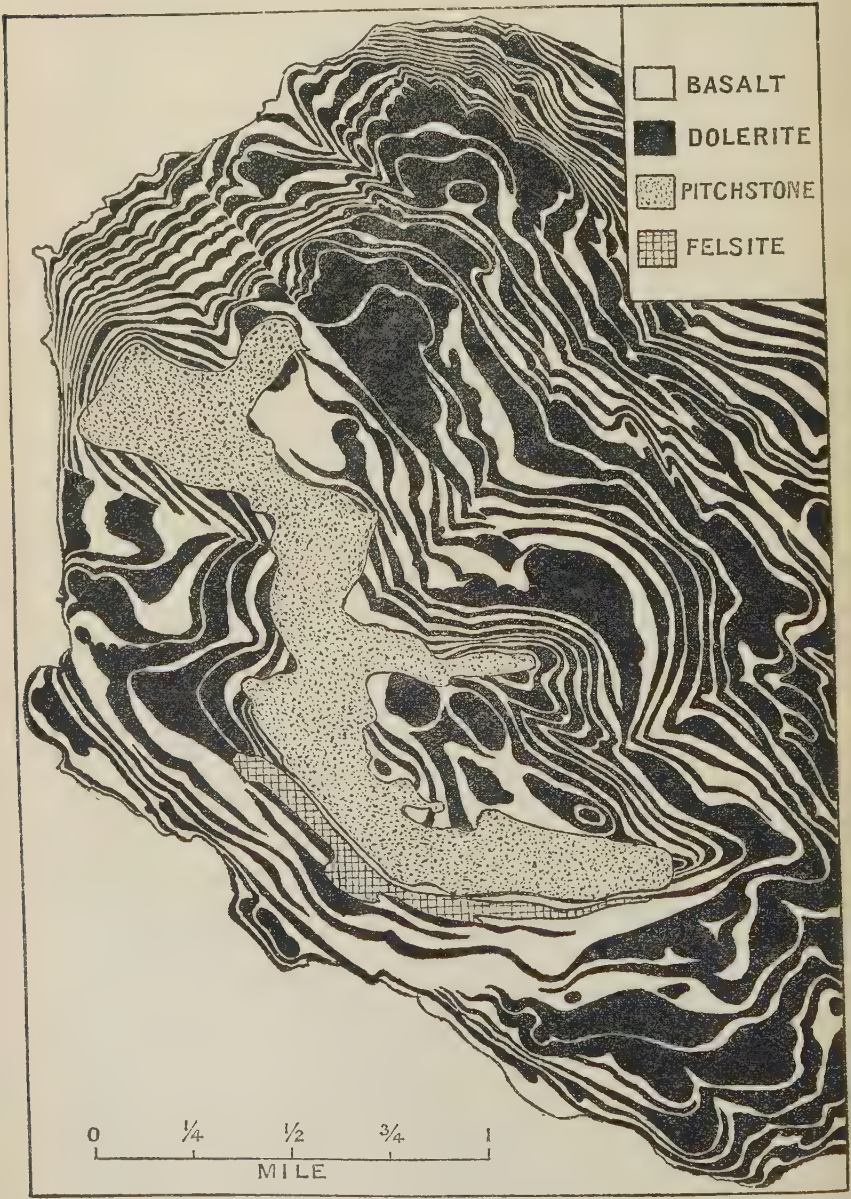
II. General Structure of the Pitchstone-Complex.

The general geological structure of Eigg is too well known to need any detailed account in this place. The Jurassic strata displayed in the northern part of the island have sunk below sea-level in the southern part; and here the crumbling basalts, and the more durable dolerite-sills which alternate with them, rise inland in a terraced slope, culminating in the Sgùrr. Resting on this pile, as if poised upon a pedestal, is the great mass of the pitchstone. Its crowning position and its abrupt outline make it a conspicuous object, even in a distant view. The bold ridge which it makes has a curved course with a general direction from north-west to south-east, terminating abruptly at the highest point (1289 feet). Excepting this most elevated portion to the south-east, the crest of the ridge runs usually at an altitude of 1000 to 1100 feet. The pitchstone presents generally precipitous walls on both sides: its base on the north-eastern side being in most places between 900 and 1000 feet above sea-level, while on the opposite side it sometimes sinks to 700 feet, showing a general inclination in this direction (south-westward or southward). The base also declines along the direction of the ridge, being at about 1060 feet at the easterly termination, and sinking to about 550 feet at the opposite end, where the ridge is truncated by sea-cliffs. There are also minor variations of level, and it is clear that the lower surface of the pitchstone has in places an undulating form. The breadth of the ridge varies up to about 500 yards, exclusive of some arm-like extensions on the north-eastern side, which make the hills named Beinn Tighe and Cornbheinn. The maximum thickness of the pitchstone is about 400 feet. In its south-eastern portion the base, in so far as it can be regarded as an inclined plane, has a general dip of about 15° to the south. At the actual termination eastward the inclination is much steeper, the observed dip being about 40°.

The fine natural section at this last-mentioned place shows clearly that the pitchstone truncates obliquely the alternations of basalt and dolerite upon which it rests (see Pl. III). The same is true in every part of the boundary, as is well brought out by the mapping of the hill. The relation of the pitchstone to the underlying rocks is, then, of a transgressive kind. Further, the partly undulating form of the surface of contact is not due to any subsequent folding; for the basalt-group below is undisturbed, with a gentle south-westerly dip. (See map, fig. 1, and section, fig. 2, pp. 44 & 45.)

The rocks which build the Sgùrr are not a single body, but constitute a number of sheets, which in most places are sharply divided from one another. The dominant rock is the well-known porphyritic pitchstone, containing clear crystals of felspar in a velvety-black resinous-looking groundmass. Intercalated in this are sheets, usually of no great thickness, composed of a dull-grey porphyritic felsite, which, as seen in the escarpment, weathers more rapidly than the pitchstone, and so forms grooves or recesses

Fig. 1.—*Sketch-map of the south-western part of the Isle of Eigg, on the scale of 2 inches to the mile.*



[The above map shows how the pitchstone truncates obliquely the basalt-and-dolerite succession; also the position of the Grulin felsite-intrusion, possibly representing the feeder of the pitchstone.]

Fig. 2.—*Section through the south-eastern part of the Sgùrr of Eigg, near the summit, in a direction S. 10° W.–N. 10° E. (Scale: 6 inches = 1 mile.)*

[The symbols have the same signification as those on the map, fig. 1. The minor undulations of the base of the pitchstone are omitted.]

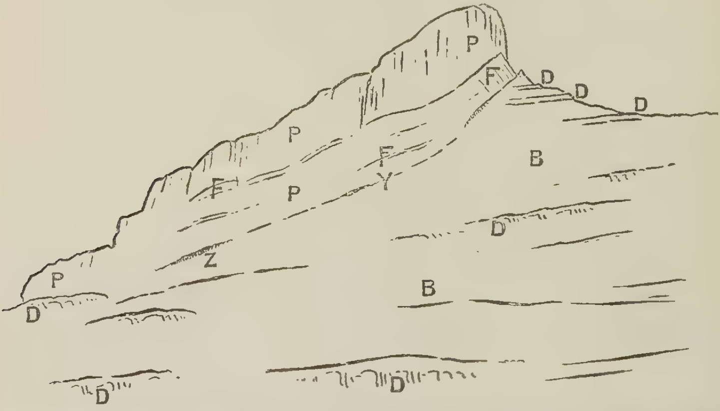
in the face of the wall. This rock differs from the pitchstone chiefly in having a compact stony groundmass instead of one largely made up of glass, and the two rocks are beyond doubt closely related to one another. In places there is indeed, as we shall notice, a gradual transition between them. The felsitic sheets come in at various horizons in the complex, but are more abundant in the lower parts. They are best seen in the higher eastern portion of the ridge, and especially in its southerly face. They are not continued indefinitely, but die out in the pitchstone. The latter rock, so far as any visible evidence goes, may be a single mass from top to bottom.

The pitchstone and its felsitic modification, taken together, are clearly the youngest igneous rocks in this neighbourhood. Not only are the subjacent basalts and dolerites obliquely cut off at the face of junction, but also, as Sir Archibald Geikie remarked, certain basalt-dykes, which intersect these lower rocks, terminate abruptly at the same surface. Further, the 'plateau'-faults, which displace the basalts and dolerites, do not affect the pitchstone.

At the base of the

pitchstone-complex there is seen in many places a rock which at first sight seems to be quite distinct, though evidently related to the complex above. It shows more or less abundant blocks of the black pitchstone in a soft pale-grey matrix, which is evidently formed by the decay of the pitchstone itself or of its felsitic modification. The weathering-out of this soft basal band has often given rise to a recess at the foot of the pitchstone-escarpment (see Pl. III & fig. 3, YZ; also fig. 5, p. 57). It is well seen along the southern face for a distance of 500 yards from the eastward termination of the ridge, its thickness here being usually from 3 to 7 feet, or exceptionally as much as 10 feet. The pitchstone-blocks embedded in the soft pale-grey matrix range up to a

Fig. 3. (*Key to Pl. III.*)—*The Sgùrr of Eigg seen from the east-south-east, from near Galmisdale.*



The lower slopes are made by numerous alternations of basaltic lavas (B) with intrusive sills of dolerite (D). These are truncated obliquely by the thick sheet of pitchstone (P) which forms the summit-ridge, having a columnar structure in a roughly vertical direction, or locally inclined and divergent. The pitchstone is intersected by thinner sheets of a felsite (F), the devitrified equivalent of the pitchstone itself, with a generally parallel disposition but deviating in places.

Along the line YZ is a recess made by the weathering-out of the brecciated and decayed basal band of the pitchstone, and below this at Z is the breccia with foreign rock-fragments and fossil wood.

foot or two in diameter, and exceptionally to 4 feet. Their varying orientation, as indicated by the flow-structure in them, proves that they are not merely relics of an unbroken sheet, but have suffered relative displacement. Sir Archibald Geikie considered this decayed band to represent 'a kind of brecciated base or flow of the main pitchstone-mass,'[1] and this is doubtless its true nature. It is very clear in places where, for a short distance, the base of the pitchstone

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 307.

has escaped breaking up, and the pale band is seen abutting upon undisturbed and unaltered rock (see P[1] in fig. 6, p. 60). In addition to the blocks of pitchstone (and felsite), the decomposed matrix encloses in places a few pieces of a blacker and more completely vitreous rock, without conspicuous felspar-crystals, which may be taken to represent a more perfectly glassy selvage to the pitchstone-sheet. There are also fragments of extraneous origin, which are sometimes rather abundant at the base of the pale band, but become rare towards its top. Excepting one locality, to be described below, these extraneous fragments are exclusively of basalt and dolerite, evidently picked up from the subjacent rocks. The inclusion of these is not necessarily connected with the brecciation, for they are found also in the base of the pitchstone where it is unbroken and unaltered: for example, in the spur on the north-eastern side of the ridge near Loch na Mnà Moire.

The general geological relations of the pitchstones to the basic rocks have at different times received very different interpretations. Macculloch[1] (1819) does not explicitly discuss the point. He remarks that the rock of the Sgùrr may in places be

'seen resting on the same trap with which it alternates, and thus forming . . . . the uppermost rock of this interesting island.'

The 'trap' here referred to is the felsite which is so intimately bound up with the pitchstone itself; but the concluding words seem to imply that pitchstone and felsite together constitute merely the uppermost member of the general sequence. This ignores the obviously transgressive junction, so clearly exhibited at the eastern end of the ridge.

Von Œynhausen and von Dechen[2] (1829), as appears from their brief reference and the accompanying figure, considered the pitchstone to be intruded through the basalts, and indeed they liken it to a dyke. Hay Cunningham[3] took the same view, which he illustrated by a most uncompromising diagram; and James Nicol[4] arrived at a like conclusion. It is difficult to understand how this dyke-hypothesis could ever be entertained, in view of the manifestly stratiform disposition of the pitchstone-mass. At numerous places along the base it is possible to penetrate for several yards under the great sheet, and to see its base, like an inverted pavement, overhead.

Hugh Miller (1858), like Macculloch, realized that the pitchstone definitely overlies the basalts; and, though his words are more picturesque than precise, he seems to have regarded it as the result of a volcanic outpouring. He speaks of the rock of the Sgùrr as having been 'laid down . . . . in one fiery layer after another'.[5] It is, however, to Sir Archibald Geikie[6] (1865) that we owe a clear

[1] 'Description of the Western Is. of Scotland' vol. i (1819) p. 522.
[2] Karsten's Archiv für Min. vol. i (1829) pp. 105–14 & pl. iv.
[3] Mem. Wern. Nat. Hist. Soc. vol. viii (1839) pp. 144–63 & pl. v.
[4] 'Guide to the Geology of Scotland' 1844, pp. 232–33.
[5] 'Cruise of the *Betsey*' 1858, p. 35.
[6] 'Scenery of Scotland' 1st ed. (1865) pp. 278–82; Journ. of Travel & Nat. Hist. vol. i (1868) pp. 14–16; Quart. Journ. Geol. Soc. vol. xxvii (1871) pp. 279–310; and later works.

exposition of the view which regards the pitchstone of the Sgùrr of Eigg as a lava-flow, or succession of flows, poured out over an eroded land-surface of the basalts. This may be taken as the generally accepted interpretation for the last forty years. It has been endorsed by Prof. Judd,[1] Prof. Heddle,[2] and others; but it does not appear to have been critically tested on the ground.

In 1892 the late Prof. Heddle[3] made an interesting contribution to the subject, recognizing that a porphyritic pitchstone identical with that of the Sgùrr of Eigg makes the isolated cluster of low rocky islets named Oigh-sgeir (often written Hyskeir); an observation subsequently confirmed by Sir Archibald Geikie.[4] Oigh-sgeir, rising only 34 feet above sea-level, lies between 18 and 19 miles from Bidein Boidheach, the seaward termination of the ridge of the Sgùrr, and bears about W. 15° N., agreeing with the general trend of the pitchstone-ridge of Eigg. If, as Heddle supposed, Oigh-sgeir and the Sgùrr of Eigg are relics of one and the same lava-stream, we must infer that the two islands formed, at the epoch of the pitchstone, parts of one extensive land-surface. Assuming that the nearly submerged pitchstone of Oigh-sgeir has a thickness comparable with that seen on Eigg, Sir Archibald calculates that the base declines westward at the rate of about 35 feet per mile.

When, in the course of the geological survey of the Inner Hebrides, the present writer came, in 1903, to map the southern part of Eigg, the work was begun on the received hypothesis that the pitchstone of the Sgùrr represents the remains of a lava-current filling an old Tertiary river-valley. The detailed examination of the ground, however, discovered circumstances which were difficult to reconcile with that hypothesis, and eventually led to a reconsideration of the whole question. The results of my observations, though not sufficient to decide some of the minor questions which arise, go to support the view that the pitchstone-sheet is intrusive in the basalt-group. I have twice revisited Eigg during the present year (1905), and on one visit had the advantage of accompanying Dr. Peach, who brought to light other facts tending to the same conclusion. I am indebted to him for useful criticism, as well as for positive additions to the evidence bearing on the question. I desire also to express my thanks to Mr. R. L. Thomson, the proprietor of the island, who has interested himself in the enquiry, and whose kindness has made the work easy and pleasant.

The first point relates to the general form of the pitchstone-complex as a whole. The elongated and curving trend of the ridge,

[1] Quart. Journ. Geol. Soc. vol. xxx (1874) p. 267.

[2] Proc. Roy. Soc. Edin. vol. xi (1882) pp. 632–33; also (Appendix C) 'A Vertebrate Fauna of Argyll & the Inner Hebrides' by J. A. Harvie-Brown & T. E. Buckley, 1892, pp. 247–50.

[3] *Op. supra cit.* p. 249.

[4] Rep. Brit. Assoc. for 1894 (Oxford) pp. 652–73; and Quart. Journ. Geol. Soc. vol. lii (1896) pp. 371–73.

with its projecting arms, seems at first to accord with the supposition that the pitchstone occupies an old valley with smaller tributary glens; and it is also very noticeable that, at the base of the escarpment, the lower surface of the pitchstone has in most places an inward slope. Even on a broad view, however, the actual courses of the supposed valley and its tributaries are not easily laid down on any plausible lines; and the main valley must be supposed to narrow to a gorge at Bidein Boidheach, although it is in this part of its channel that the assumed river-gravel has been accumulated to a depth of about 100 feet (see Pl. IV & fig. 4, p. 53).

Closer examination of the actual sections raises more serious difficulties in the way of this hypothesis. The junction of the pitchstone with the underlying rocks is sometimes a steeply-inclined surface, and in certain parts of the boundary it slopes outward. This is very noticeable near Loch Beinn Tighe, where there is a sharp dip down towards the tarn. In the south-western part of Beinn Tighe the base of the pitchstone inclines towards the main body; but in the north-eastern part of the hill the dip is in the opposite direction, implying that the supposed tributary at this place ran uphill. The same is true of the smaller projecting tongue between Beinn Tighe and Cornbheinn. Along Cornbheinn the base of the pitchstone has apparently an undulating inclination, without any general slope towards the west; nor is it easy to see how the supposed tributary glen at this place could enter the main valley. Similar difficulties are encountered at places on the opposite side of the main ridge, notably at the projecting spur north of the Grulin crofts.

The detailed mapping of the ground thus leads to a different interpretation of the structure of the Sgùrr. The ridge and its offshoots, as we now see them, seem to be rather the relics of a more extensive sheet which had an irregularly-undulating lower surface. The position of the escarpment in different places has been determined by lateral erosion operating in relation to the columnar jointing which is so striking a feature of the pitchstone-complex. Where the columns leaned outward, they were easily destroyed, and the escarpment was thus cut back to a line along which the columns leaned inward. This corresponds as a rule with an inward dip of the base of the sheet, since the columns tend usually (but with exceptions) to be perpendicular to the lower surface. The exceptions are seen at such places as Loch Beinn Tighe, where the columns lean inward, although the base of the pitchstone dips outward.

The visible form of the lower surface of the pitchstone-complex, as seen in detail along all parts of the base of the escarpment, is a highly significant one. The pitchstone, as we have seen, truncates an alternating succession of basalts and dolerites, the latter of which are much more durable rocks than the former. The slope leading up to the Sgùrr, or any other hillside in the plateau-region, shows accordingly a strongly terraced form which is very characteristic, and is well seen in Pl. III. Such should be the form of the base

of the pitchstone, if it coincided with an old surface of erosion. The actual form, as shown in the same plate, is very different. Despite undulations, the junction is always a clean-cut one. The undulations may often be seen to correspond with the places where the pitchstone-base passes from basalt to dolerite; but they show only gentle curvature, never abrupt change of direction. In this the junction agrees with an intrusive one, and differs from the erosion-form which is a necessary part of the river-valley hypothesis.

The steep inclination of the base of the pitchstone in certain places has already been remarked. Exceptionally, as on the north side of the Bidein-Boidheach section, it seems to approach the vertical. But it is further to be noticed that a steep slope is sometimes found in individual sheets of the complex, which on the extrusive hypothesis should represent separate lava-flows. The most conspicuous example is the eastern precipice of the Sgùrr proper (see Pl. III). Here the base consists of a sheet of felsite some 30 feet thick, with parallel upper and lower surfaces, which dips southward at an angle of 40°. It is clear that a thin lava-flow could not rest in such a posture as this, and examination of the felsite leaves no doubt that it is intrusive. It truncates obliquely the columns of the overlying pitchstone; and, when followed down the southern slope, it is seen to leave the base, cutting into the pitchstone itself and running out into two tapering tongues.

Other sheets of felsite, which are numerous on the southerly face of the eastern part of the ridge, show in different cases indications of intrusive relations towards the pitchstone. A small one near the base passes into a nearly vertical dyke cutting up into the pitchsone. Most of the sheets have an approximately horizontal position, but with a wavy course and tapering form,[1] and bifurcation may be observed in several places. The felsites do not share the regular columnar structure of the pitchstone, but often truncate the columns obliquely, while they have a less pronounced and ruder jointing perpendicular to their own contact-surfaces. These circumstances seem to afford satisfactory evidence of intrusion.

We have remarked, however, that there are also gradual transitions between felsite and pitchstone; and it is of interest to note that this relation is sometimes to be observed in connection with sheets of felsite which still give evidence of being intrusive in the pitchstone-mass. The sheet first mentioned, at the eastern base of the Sgùrr, is probably an example of this, for, where it bifurcates towards the south, it seems to lose itself gradually in the pitchstone. In several other cases, which can be more closely scrutinized, such behaviour is quite manifest. A sheet which sharply cuts the pitchstone can be followed along its length until the line of demarcation is lost, and the felsite merges into the general body of the pitchstone

[1] See Sir Archibald Geikie's sketch, Quart. Journ. Geol. Soc. vol. xxvii (1871) pl. xiv, fig. 3.

by insensible gradations. Such a sheet would seem to represent a portion of magma forced out from a place where solidification was not yet complete and piercing a part of the mass which had already consolidated as pitchstone. The relationship between the two rocks must thus be of a peculiarly intimate kind, since they are on this supposition products of one magma, intruded in the first place as a single body.

It would not follow from the relation suggested that the felsite-sheets should agree exactly in chemical composition with the pitchstone (which itself seems to be somewhat variable) or with one another. Indeed the crystallization of the felsite and the vitrification of the pitchstone may be determined, in part, by a certain difference in composition. The following partial analyses are furnished by Dr. W. Pollard, the felsite being from the conspicuous sheet at the eastern base of the Sgùrr:—

	Pitchstone.	*Felsite.*
SiO_2	63·34	68·43
Na_2O	4·56	4·76
K_2O	4·50	6·31

Another consideration relates to the channel by which the pitchstone ascended through the basalts. We may safely assume that the magma which gave birth to the rock possessed a considerable degree of viscosity. As a subaërial lava it could not flow to any very great distance. If it was a subterranean injection, the same remark applies, though with somewhat less force. Among our Tertiary intrusions, sheets of acid or subacid composition, although they may equal or exceed the dolerite-sills in thickness, in no case rival them in lateral extent. On either alternative, then, we might hope to find some indication of the source of the pitchstone at no great distance from the Sgùrr itself. On the lava-flow hypothesis we should seek such indication in an easterly or south-easterly direction. Here we find no intrusive mass which can be supposed to mark the channel of uprise; but, since we arrive at the sea in a distance of about $1\frac{1}{2}$ miles, the negative evidence is of little weight. Close to the ridge of the Sgùrr, however, on its south-western side, we find a remarkable intrusion of porphyritic felsite, which may possibly represent the feeder of the pitchstone-intrusion. This mass, recognized by Sir Archibald Geikie and marked on his sketch-map,[1] has an elongated form, and extends for more than a mile close to the base of the pitchstone-escarpment (see map, fig. 1, p. 44). In its western or north-western part, above the deserted crofter townships of Grulin, the outcrop has a width of 100 to 200 yards, and it is evident that the rock cuts abruptly through the basalt-lavas and dolerite-sills with a quasi-vertical boundary (see section, fig. 2, p. 45). Eastward, near the summit of the Sgùrr, the outcrop tapers away, and it is possible that the mass has in this part the form of an inclined sheet. The rock is not only later than the dolerite-sills,

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 286.

but probably also later than the basic dykes; for one at least of these stops abruptly on encountering the felsite, as if cut off by it. So far as the evidence goes, therefore, this Grulin felsite may well be of the same age as the pitchstone. The felsitic rocks near Laig Farm and at the extreme north of the island are earlier, being intersected by the basic dykes; and they are thoroughly acid rocks, while the Grulin felsite is essentially felspathic. Otherwise unique in the district, this rock has petrographical characters in common with the felsite-sheets of the Sgùrr, although, as is to be expected, it is not of such fine texture. A partial analysis by Dr. Pollard enables us to compare its composition with that of the pitchstone:—

	Pitchstone.	*Grulin felsite.*
SiO_2	63·34	58·13
Na_2O	4·56	4·57
K_2O	4·50	4·85

The resemblance in respect of the alkalies is very close.

III. Fragmental Accumulations and Fossil Wood.

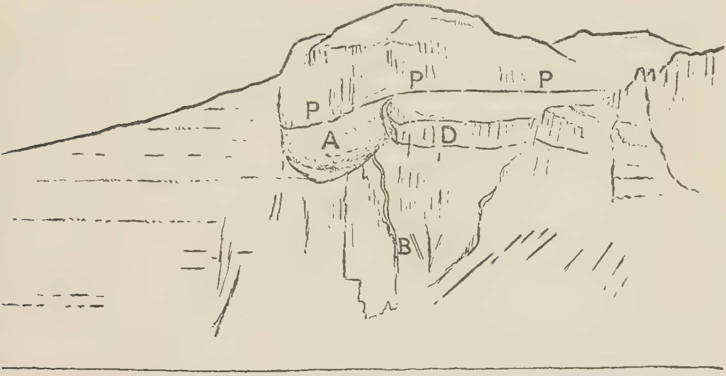
In two places accumulations of fragmental materials are seen immediately beneath the pitchstone, or beneath the pale decomposed band which has been included as a component part of the pitchstone-complex. These fragmental accumulations are of importance, as constituting a part of the evidence upon which Sir Archibald Geikie has based his interpretation of the structure of the Sgùrr of Eigg. He considered them to be of the nature of river-gravels, laid down on the floor of a valley at this place, and subsequently covered by a pitchstone lava-stream. The two localities present different features, and will be described separately.

We take first the section at Bidein Boidheach, where the ridge, running north-westward, is abruptly cut off by the sea-cliffs. Sir Archibald Geikie has given a figure[1] of this place, and by the kindness of Mr. A. S. Reid, F.G.S., I am enabled to illustrate it by a photograph, taken by him, under considerable difficulties, from the sea (Pl. IV and fig. 4, p. 53). The lower part of the section shows the usual alternations of basalt-lavas and dolerite-sills lying nearly horizontally. At the top is the pitchstone-sheet, its base at this place dipping inward on both sides of the ridge in a way which, taken alone, might seem to accord well with the supposition that the pitchstone occupies the bed of a valley. Below this, and filling a hollow in the basalt-group, is the fragmental accumulation to be noticed. As seen in the cliff-section, it has a maximum thickness of perhaps 100 feet, rapidly thinning away in both directions. It might represent either a cross-section of a deposit extending along the direction of the ridge, or a small funnel-shaped mass which happens to be intersected by the present line of the cliff. I interpret

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 308.

it in the latter way, as a mass of volcanic agglomerate filling a small vent. Only a small part of it, on the south side, is accessible to direct observation.

Fig. 4. (*Key to Pl. IV.*)—*Bidein Boidheach, showing the sea-cliff in which the ridge of the Sgùrr terminates north-westward.*



The outcrops of the basaltic lavas and dolerite-sills run in nearly horizontal lines. PPP is the base of the pitchstone, and A is the volcanic agglomerate which underlies it in the cliff. The dolerite-sill D, impinging upon the agglomerate and deviated by it, is not distinctly seen in the photograph. At B are basalt-dykes, cutting the basalt-lavas and dolerite-sills, and one of these is seen to terminate abruptly at the agglomerate.

The first point to note is the evidence that this fragmental accumulation is older than the dolerite-sills. The large sill which makes the top of the cliff on the south side is seen to abut upon the agglomerate, but does not enter it. It is, however, not cut off, but sharply deviated. As Dr. Peach observed, it turns upward, with diminished thickness, along the boundary of the agglomerate, and then, curving away, rapidly dies out. No corresponding sill is seen on the opposite side, although the unbroken succession below shows that the steep boundary on that side is not made by a fault. Instead we find some thinner sills which, so far as can be seen, appear to terminate abruptly at the agglomerate. The sharp deviation or abrupt termination of sills where they come against a mass of coarse agglomerate is a phenomenon seen in many places in Skye, Canna, and Sanday. These and some other massive rocks appear to have the property of arresting the progress of a minor intrusion, either sill or dyke, which encounters them.[1] Some basalt-dykes occur, as noted by Sir Archibald Geikie, in the cliff of Bidein Boidheach, and one of them is seen to terminate abruptly at the

[1] See 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, pp. 242, 293.

agglomerate. Since it cuts the dolerite-sills, it cannot be older than the agglomerate, and its apparent truncation must be due to the difficulty which it experienced in piercing that mass. Both in its form and in its relations this fragmental accumulation of Bidein Boidheach closely resembles some of the small volcanic vents of Skye, notably one in the cliff at Sgùrr-an-Duine, between Lochs Brittle and Eynort.

The nature of the material is also in accord with this interpretation. The principal element is amygdaloidal basalt, in blocks measuring up to a foot or two in diameter, subangular or rounded; the rounding being of the kind characteristic of our volcanic agglomerates, that is tending to the spherical form, without the ovoid shapes so common in waterworn pebbles. Torridonian rocks, in smaller pieces, are fairly plentiful, and Sir Archibald Geikie found fragments of the white sandstone of the Oolites. Both formations are doubtless in place below sea-level at this locality, and the occurrence of their fragments in a volcanic agglomerate is very natural. Dr. Peach detected also a piece of granite and other fragments of a decayed rock, probably of the gabbro-family. These plutonic rocks occur also in the volcanic agglomerates of Skye,[1] and possess a certain interest, which lies, however, outside our present subject. The most significant fact is the absence of any fragments of dolerite from the sills. In a river-gravel derived from the erosion of the basalts and dolerites the latter should be as abundant as the former, or more so in virtue of their superior durability. The character of the material, therefore, confirms the conclusion that we have to do here with a volcanic agglomerate of the basalt-period, much older than the dolerite-sills and very much older than the pitchstone. The conjunction of the pitchstone with the agglomerate is, on this view, merely accidental.

The second locality to be examined is near the other end of the ridge, on the southern side of the higher part of the Sgùrr and about a quarter of a mile from its easterly termination. It is somewhat above the former occurrence, both in altitude and as regards geological horizon. In this neighbourhood the brecciated and decayed base of the pitchstone has been cut back to make a recess or piazza, in places 10 feet or more in height. In the floor of this recess a breccia with fragments of various rocks is poorly exposed for some distance; and at one place, near some shelters for sheep, is the locality of the well-known fossil wood.

Although the fossil wood of the Sgùrr of Eigg was discovered 90 years ago, and has been referred to by numerous writers, the published information concerning its mode of occurrence is not only very scanty, but remarkably confused. This is due partly to misunderstanding of records obtained at second-hand, partly to the fact that wood occurs at this place in more than one situation and of more than one kind.

[1] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 24.

The earliest notice is by Macculloch (1814). He states that the pitchstone lies in a bed of 'marle' 3 or 4 feet thick, which rests upon a bed of hard reddish sandstone, and that

'Large masses of wood, bituminized and penetrated with carbonat of lime, are found in the marle stratum, not at all flattened. Portions also of trunks of trees, retaining their original shape, are seen in the same bed, silicified, and their rifts filled with chalcedony, approaching in aspect to semi-opal.'[1]

Later[2] he made a correction, stating that what he had termed 'marle' was a 'mixture of limestone, clay, and sand.' He found reason to believe that it was not a continuous bed, but either a lenticle entangled between the pitchstone and the subjacent mass or a part of the latter. This underlying mass he described as

'a conglomerate consisting of small and large fragments of red sandstone, trap, and silicified wood, imbedded in a basis of trap' (*loc. cit.*).

Macculloch's 'marle' is the pale brecciated and decayed base of the pitchstone, and the 'conglomerate' below is the rock which will here be described as a volcanic agglomerate. The large pieces of wood are correctly described as occurring in the former, and Macculloch is equally accurate in recording fragments of wood in the latter also.

Von Œynhausen and von Dechen[3] apparently failed to find wood, but they unwittingly contributed to the confusion of the subject. Their paper mentions, as occurring immediately beneath the pitchstone on the south side, a conglomerate with pieces of pitchstone, hornstone, chalcedony, and calcspar; and this they identify with Macculloch's conglomerate containing red sandstone etc., though it must certainly be the brecciated and decomposed base of the pitchstone.

Fossil wood from beneath the Sgùrr of Eigg was described and figured by Witham[4] (1831), and shortly afterward by Lindley & Hutton.[5] From both accounts it might be inferred that this wood, named *Pinites eiggensis*, occurred in place in Jurassic strata at the base of the Sgùrr. This misapprehension was corrected by William Nicol,[6] who had supplied the material described, and who states that it was found 'among the débris of the prismatic columns of porphyritic pitchstone.' The specimens described and figured, then, were not obtained *in situ*, but from loose fragments. It is fairly certain, however, that their source was the former of the two occurrences recorded by Macculloch, namely, the decaying base of the pitchstone.

[1] Trans. Geol. Soc. ser. 1, vol. ii (1814) p. 408.
[2] 'Description of the Western Is. of Scotland' vol. i (1819) p. 522.
[3] Karsten's Archiv für Min. vol. i (1829) p. 107.
[4] 'Observations on Fossil Vegetables' 1831, p. 37 & pl. v, figs. 13–14. Also 'The Internal Structure of Fossil Vegetables' 1833, pp. 63–65, pl. xiv, figs. 13–14, & pl. xv, figs. 6–9.
[5] 'The Fossil Flora of Great Britain' vol. i (1831–33) pp. 91–92 & pl. xxx.
[6] Edin. New Phil. Journ. vol. xvi (1833) p. 154. See also Rep. Brit. Assoc. for 1834 (Edinburgh) Trans. Sections, p. 660.

Hay Cunningham,[1] upon no grounds ascertainable from his memoir, flatly contradicts Macculloch's statements as to the mode of occurrence of the fossil wood. He asserts that the wood has never been found *in situ*, and adds, inconsequently,

'it is evident from the point where its fragments may be obtained, that its matrix is the rock of the Scuir......'

Hugh Miller described quite clearly the manner of occurrence of the wood, as follows:—

'We were successful in procuring several good specimens of the Eigg pine, at a depth, in the conglomerate, of from 8 to 18 inches. Some of the upper pieces we found in contact with the decomposing trap out of which the hollow piazza above had been scooped; but the greater number ...... lay imbedded in the original Oolitic grit in which they had been locked up ......'[2]

It is to be remarked that at that time, notwithstanding Macculloch's earlier work, the basaltic rocks were generally believed to be lavas of Oolitic age. Assuming this, Miller included the conglomerate in the same series, and regarded the fossil wood as the relics of contemporaneous vegetation entombed in the 'deep-sea bottom.' Not only did he speak of the Eigg pine as 'an ancient tree of the Oolites,' but he stated that it is found in this formation in other parts of Scotland:—

'The fossil trees found in such abundance in the neighbourhood of Helmsdale that they are burnt for lime,—the fossil wood of Eathie in Cromartyshire, and that of Shandwick in Ross—all belong to the *Pinites eiggensis*' (*op. cit.* p. 39).

It does not appear, however, that this statement was based on any minute comparison of specimens; and, indeed, in a later work Miller did not insist upon the specific identity, but spoke of the examples from the eastern part of Scotland as 'branches and portions of the trunks of a similar pine' to that of Eigg.[3] It should be noted that Miller's Eigg specimens came partly from the decomposing base of the pitchstone, but mostly from the underlying breccia or agglomerate. My own specimens from the latter situation include some which do not belong to *Pinites*; but small pieces of this also occur here, as well as in the band above.

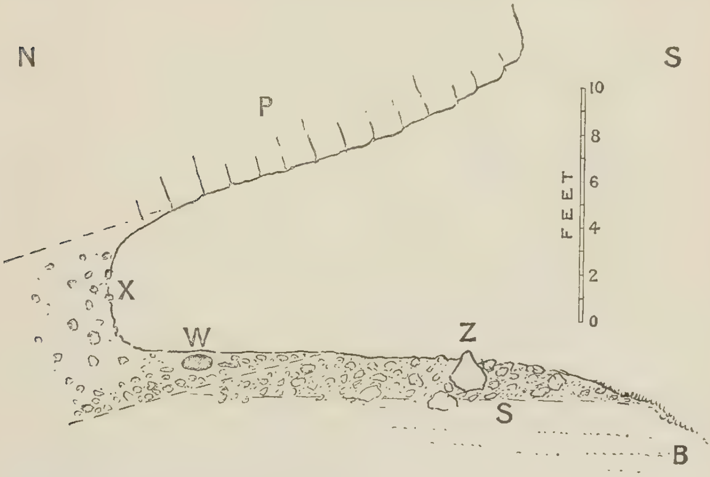
Sir Archibald Geikie[4] seems to have found only the small pieces of wood which occur mingled with fragments of various rocks in the breccia, as distinct from the brecciated and decaying base of the pitchstone, although his brief account does not explicitly separate the two fragmental bands which occur at this place. I have no doubt that the two are quite distinct, and that their conjunction here is accidental. The brecciation of the basal part of the pitchstone (or its felsitic modification) and alteration to a soft

[1] Mem. Wern. Nat. Hist. Soc. vol. viii (1839) p. 156.
[2] 'Cruise of the *Betsey*' 1858, p. 37.
[3] 'Sketch-Book of Popular Geology' 1859, p. 138.
[4] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 307.

rock of dull-grey aspect may be seen for long distances in many parts of the escarpment of the Sgùrr. The breccia below, composed largely of non-volcanic material, is a local accumulation, which is seen at this place for a length of perhaps 50 yards. Moreover, I shall offer reasons for believing that it is interbedded in the basalt-group, and therefore does not follow the irregular base of the pitchstone.

The locality has sufficient interest to merit a more particular description. It is clearly the same as that which was visited by Macculloch, Miller, and others; and the fossil wood preserved in various collections has doubtless come from this place. Despite

Fig. 5.—*Section at the southern base of the pitchstone, about a quarter of a mile west of the eastward termination of the ridge.*



P = Base of fresh columnar pitchstone.
X = Brecciated and decayed pitchstone, enclosing blocks of the fresh rock and rare pieces of other rocks.
Z = Breccia, with blocks and fragments of foreign rocks.
W = Large log of fossil wood.
S = Horizon of sandstone and plant-bed seen farther east.
B = Basalt-series below.

Hugh Miller's allusion to a 'prostrate forest' underlying the pitchstone, I cannot learn from the published accounts, from the information of residents, or from personal search, that wood has ever been discovered under the Sgùrr, except at this place; and the large pieces of pine which have been obtained at different times may very possibly be portions of a single tree. To exhibit the relations of the rocks, as well as to procure good specimens of the wood, some work with pickaxe and spade is necessary. Excavations have been made

under my eye on two occasions, once in the presence of Dr. Peach; and Mr. D. Tait, who visited the place to collect for the Geological Survey, has also furnished me with some notes to supplement my own.

The base of the fresh columnar pitchstone, forming the roof of the recess or gallery, has, as usual, an inward dip, although the general inclination of the great sheet is, in this part of the Sgùrr, in the opposite direction. The base of the pale decomposed band (X in fig. 5, p. 57) has a similar dip, and the thickness of the band is here about 7 feet. As elsewhere, it contains, besides the blocks of unaltered pitchstone and felsite, some pieces of basalt, which become more abundant in the lowest part. In addition we find, what are not seen elsewhere, fragments of Torridon Sandstone and little pieces of fossil wood. In the lower part of the pale decomposed pitchstone, but distinctly enclosed in it, occurs the main mass of wood (W) which has furnished the specimens of *Pinites eiggensis*. There can be no doubt that this (as well as the Torridonian fragments) has been taken up from the underlying breccia presently to be described. Most of the wood, both in the main mass and in the scattered pieces, is completely silicified, of a lustrous black, and often shot through with slender threads of white calcite; but there is some which is not silicified, being more or less carbonized, with a similar black lustrous aspect. Mr. Tait's account is as follows:—

'Here a log of fossil wood lies embedded, with its length parallel with the length of the Sgùrr. The piece is about 5 feet long, as it now remains. [I subsequently saw about 8 feet exposed.—*A. H.*] Probably the heavier end of the log lies towards the east, but this could not be definitely ascertained. The log is about 8 inches in vertical height, and somewhat more in horizontal breadth: this gives it a flattened oval outline in transverse section. It is cracked and fissured in many directions, and pieces evidently belonging to this trunk are completely separated from it. That these pieces do belong to this trunk is seen by their similarity of texture and their orientation...... Numerous fragments of smaller branches occur at this level. They are often flattened into ribbon-shaped pieces, that lie flat on the bedding-planes. At places 15 to 20 yards apart the matrix in which the wood is embedded is quite different. In this woody layer, small angular stones are embedded. These stones increase in number and size downwards, and so form the underlying breccia exposed at the outer edge of the platform.'

The last sentence would imply a passage from the pale band of decomposed pitchstone (X) to the underlying breccia or agglomerate (Z). Dr. Peach and I satisfied ourselves that there is a clear separation between them, although the pieces of extraneous rocks in the former naturally become more numerous at its junction with the deposit which supplied them. This deposit (Z) is of a very variable character. It consists chiefly of fragments of various sizes, with a smaller proportion of matrix, which is not always of the same nature. Sandy or basaltic (perhaps ashy) material may predominate, and there may or may not be sufficient calcareous and ferruginous matter to make a binding cement. The fragments are of red sandstone and other Torridonian rocks and of basalt,

the relative proportions of these two varying, though the former element is always well represented. There are angular blocks of Torridonian sandstone up to 4 feet in diameter, besides smaller fragments. Some of the pieces of basalt measure from 1 to 2 feet in diameter, and they are mostly subangular in shape. Of more local distribution in a recognizable state is the soft Oolitic sandstone. Pieces of this are abundant in places, generally in a crumbling condition, and the sandy element in the matrix of the deposit may be attributed to this source. Mingled with the pieces of Oolitic sandstone are fragments of brown wood, different from the black wood already mentioned. Other materials than those now enumerated seem to be very rare. I possess a piece of flint found here many years ago by Mr. C. S. Middlemiss.

At the spot where the section (fig. 5, p. 57) is drawn it is not possible to say whether any other deposit intervenes between the breccia with Torridonian and other extraneous débris (Z) and the underlying basalts. Some 10 yards to the east, however, a bedded sandstone is seen lying below the breccia, or constituting the lower part of it (S in fig. 6, p. 60). It encloses blocks and smaller fragments of Torridon Sandstone and basalt like those in the breccia proper, but here the matrix makes up the greater part of the mass. It is a fine-textured grey sandstone, composed of quartz-grains, with a cement mainly calcareous, though basaltic material, perhaps of the nature of volcanic ash, also enters into its composition. The thickness seen is about 2 feet. In addition to rock-fragments, the sandstone encloses abundant fossil wood, and there is a band composed almost wholly of vegetable remains in the condition of lignite. The stratification, which was indistinguishable in the coarse breccia, is here very evident; and there is a general resemblance to the thin and inconstant stratified deposits with plant-remains intercalated at various horizons in the basalt-group in Skye and other parts of the region.[1]

Sir Archibald Geikie considered the breccia to be a fluviatile deposit of the pitchstone-epoch, the sandstone-fragments being brought down by a river from more or less distant sources, and the pine-wood representing a contemporaneous vegetation. This interpretation seems, however, to involve considerable difficulties. The high proportion of extraneous fragments as compared with the local basalt, the large size and angular form of some of the blocks, and the mingling of coarse and fine material, are all difficult to explain on this hypothesis. Nor is it easy to find a source for the Torridonian and Jurassic rock-fragments. It must be remembered that the epoch of the pitchstone was long subsequent to any differential movements of elevation and subsidence known in the region: and therefore the relative altitudes of the several formations were substantially as they are to-day. We can scarcely suppose that the pre-Tertiary strata were more freely exposed at the surface then

[1] See, for instance, Sir Archibald Geikie, Quart. Journ. Geol. Soc. vol. lii (1896) pp. 341–42.

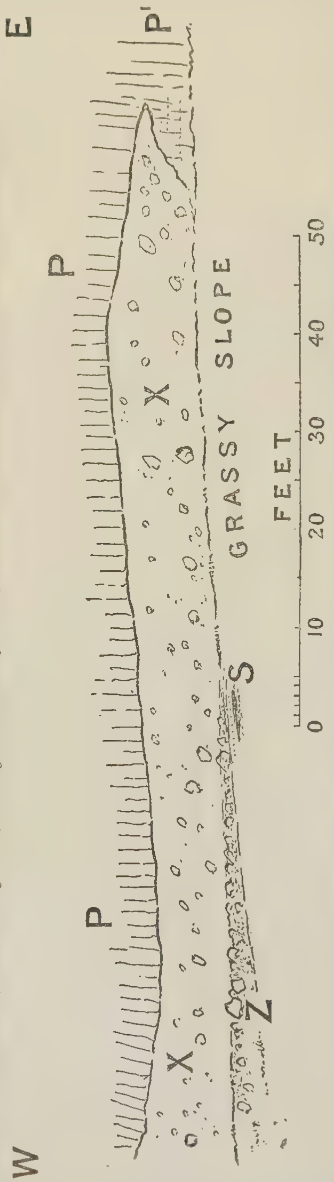
than now: the reverse is more probable. The white sandstones of the Oolites on Eigg itself are below the level of this breccia. In the cliffs of Raasay and the north of Skye they rise higher; but these places are 25 or 30 miles distant, and the abundance of the sandstone-fragments in the breccia, of which they compose at certain spots the chief element, remains unexplained. Of the red Torridonian rocks there are at the present day extensive exposures at altitudes higher than the base of the Sgùrr; but the nearest is 12 miles distant, on Rum, and we can scarcely suppose angular blocks measuring up to 3 or 4 feet in diameter to have travelled so far. Prof. Judd[1] has remarked that

> 'the characters of the buried conglomerate are suggestive of a mountain-ravine subject to the passage of violent floods rather than of an ordinary river-channel.'

To the present writer it seems to resemble more closely a volcanic agglomerate, partly rearranged by water-action.

In the volcanic agglomerates of the Inner Hebrides it is a common experience to find, mingled with the basaltic material, fragments of pre-

Fig. 6.—Section (about 40 yards) along the base of the pitchstone-escarpment, at the same locality as fig. 5, p. 57.



[The letter Z indicates the place where the preceding section is taken, at right angles to the present one.]

P = Fresh columnar pitchstone.
P¹ = Actual base of pitchstone, where it remains locally uncrushed and unaltered.
X = Brecciated and decayed pitchstone, as in preceding figure.
Z = Breccia, with foreign fragments.
S = Sandstone, with remains of contemporaneous vegetation.

[1] Quart. Journ. Geol. Soc. vol. xxx (1874) p. 267.

Tertiary rocks brought up from below by explosive action, and these sometimes exceed the basalt itself in amount. In the present case, the non-volcanic fragments that occur are such as might be expected. The Oolitic sandstones underlie the basalt-group probably a little below sea-level at this place, and below that we should confidently expect a good thickness of Torridonian strata. The occasional presence of flint, suggesting the presence of concealed Cretaceous rocks, is of some interest; for, on the coast some 2 miles to the north, Mr. Tait has detected an exposure of Cretaceous sandstone containing flints. The larger blocks in the breccia show no sign of arrangement by water-action, and the manner in which fragments of a given rock tend to cluster in one place is much more characteristic of a volcanic agglomerate than of a fluviatile deposit. Most significant of all is the fact that here, as at Bidein Boidheach, fragments of the strong dolerites are wholly wanting. This can only be interpreted as showing that the accumulation, whatever its nature, is older than the dolerite-sills, and belongs to the basalt-group, not to the epoch of the pitchstone. The visible relations at this place are scarcely sufficient in themselves to determine whether the deposit in question is interstratified in the basalt-group or behaves with the overlying pitchstone; but it is certain that no corresponding breccia is to be seen at the base of the pitchstone on the opposite side of the ridge. If, as the above evidence would indicate, this fragmental deposit is interstratified in the basalt-group, it should be found on the north side at some distance below the base of the pitchstone, unless it has died out in the interval. I sought it at this place without success. Dr. Peach, however, detected signs of it on the north side of the Gualainn, or shoulder, which forms the eastward prolongation of the Sgùrr ridge. Here, at the proper horizon but not elsewhere, are found on the surface many small pieces of Torridonian sandstone mingled with the fragments of basalt. These probably mark the occurrence of the breccia at this place, but some excavation would be required to test this point.

On the river-gravel hypothesis the deposit should occur, if at all, on the opposite (southern) side of the Gualainn; and Sir Archibald Geikie recorded an outlier of it here, resting against the denuded edges of the basalts, the stones being much more rounded and smooth than in the former locality.[1] Repeated search has not enabled me to verify this occurrence. The only fragmental accumulation to be seen here is one of Glacial origin. It consists of dolerites and basalts, with some quartz-porphyry and other foreign rocks, but without Torridon Sandstone. These rocks occur as pebbles and boulders up to a foot or more in diameter, more or less rounded, but frequently planed, and sometimes showing well-marked striation.

A distinct but related question is that of the true age of the fossil wood. Sir Archibald Geikie regarded it as the remains of

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) pp. 307-308.

contemporaneous vegetation swept down by a river of the pitchstone-epoch and entombed in a river-gravel. On the interpretation put forward in the present communication the question, how far the wood is contemporaneous, how far derived in a fossil state from older formations, is of secondary importance, but has a certain interest of its own. Tertiary wood and coal, entangled even in coarse volcanic agglomerates, are not uncommon in Skye and Canna,[1] and the Eigg wood may conceivably have a like mode of occurrence. On the other hand, it is quite possible that fossil wood might be derivative in the same sense as the fragments of sandstone with which it is associated. Examining the question on the ground, I inclined to this view so far as regards the greater part of the wood; and various considerations go to support this opinion.

It is to be noticed that three distinct kinds of fossil wood have been mentioned above as occurring at this place :—

(*a*) the black, mostly silicified, *Pinites eiggensis*, embedded in the decomposed base of the pitchstone as well as in the breccia, but evidently derived from the latter source;

(*b*) the fragments of brown wood (*Araucaroxylon*, as noted below, p. 63) associated with pieces of Oolitic sandstone in the breccia; and

(*c*) the wood associated with the sandstone of the breccia-horizon, and partly occurring as a regular bed in that deposit.

The last is manifestly contemporaneous with its matrix, and therefore of Eocene age; but concerning the other two kinds of wood the two alternative explanations may be entertained.

As regards the *Pinites*, Mr. Seward informs me that it is impossible to decide, from botanical evidence, whether it is of Jurassic or of Tertiary age. The state of preservation, however, is perhaps significant; for British Tertiary wood is not in general silicified, while that of Jurassic age frequently is. Wood is found in place in the white Oolitic sandstones on Eigg itself. At Camas Sgiotaig, a small bay near Laig, famous for its 'musical sand,' it occurs in two varieties, as represented by Mr. Tait's collection: (*a*) black and perfectly silicified; (*b*) brown and ligneous, the resemblance to the two corresponding varieties from beneath the Sgùrr amounting (to the eye) to absolute identity. It might perhaps be suggested that the big log enclosed in the decayed pitchstone derived its silica from the decomposition of that rock, and it is true that the brecciated and decayed mass in this place sometimes contains siliceous veins, like flint. But the character of the fracture seen on the detached branches and the places where they have been broken from the trunk is such as to suggest that the wood was silicified before it was broken up. Neither Mr. Tait nor myself could find any adherent matrix other than that in which the wood now lies. Nevertheless, the association of this kind of wood with that next to be noticed, both here and at Camas Sgiotaig, leads us

[1] An interesting early record is that in the old 'Statistical Account,' vol. xvii (1794) p. 293, of a log of wood embedded in the coarse agglomerate of Alman, on the eastern coast of Canna.

to group the two together as probably having the same origin and age.

The fragments of brown wood mingled with sandstone-débris in the breccia lie, as a rule, quite detached in the general matrix; but in one or two cases I thought, without being certain, that they were partly embedded in the crumbling sandstone-fragments. Moreover, one piece of wood, selected for slicing, shows the unmistakable white sandstone actually embedded in the substance of the wood, as if filling a hollow made by decay. This conclusion, in which Mr. Seward concurs, would imply that the fragments of wood have been derived, together with the sandstone, from Oolitic strata in place, and are of that age.

Mr. A. C. Seward, F.R.S., has had the kindness to examine thin slices of this fossil wood, and I am permitted to quote here the notes which he has drawn up.

Brown wood from the Great Estuarine Sandstone of Camas Sgiotaig, Eigg.

'Imperfectly preserved coniferous wood. The material is not sufficiently good to enable one to determine the nature of the plant with any certainty; it is indubitably a Conifer, and from its arrangement of pits on the radial walls of the tracheids I think that it is probably referable to the genus *Araucaroxylon*. This generic type includes *Araucaria* and *Agathis*, the two surviving representatives of the Araucarieæ, and numerous fossil species. I think it most probable that the wood is of Jurassic age.'[1]

Brown wood from breccia below the pitchstone of the Sgùrr of Eigg (Z in fig. 5, p. 57).

'In one specimen the wood contains an included patch of rock which was I believe, introduced during the decay of the tissue. The rock and wood are, I believe, contemporaneous. The generic identification is very difficult, not to say impossible, owing to the lack of well-preserved material. The characters do not agree with those of *Pinites eiggensis*, as represented by the well-preserved specimens in the British Museum (Natural History). Similar characters are shown in two other sections.'

[Another specimen.]

'Preservation very poor; but, from the occurrence of multiseriate and contiguous bordered pits on some of the tracheal walls, the wood appears to be *Araucaroxylon*. This type exists in Palæozoic rocks, it occurs in the Mesozoic and Tertiary formations, and is characteristic of the recent Araucarieæ.'

Conclusion.

'The wood from Camas Sgiotaig may be generically identical with some of the material from the Sgùrr of Eigg: both show Araucarian characters. As regards age, my impression is that the evidence favours a Jurassic rather than a Tertiary horizon. The reasons in favour of this view are (i) the fact that Araucarian wood is very abundant in Jurassic rocks (for example, the Liassic rocks of Whitby, where this type of wood appears to have been mainly responsible for the production of jet; Araucarian plants also occur in some abundance in Inferior Oolite rocks); (ii) the nature of the material, which is more like that known to occur in Jurassic than in Tertiary strata.'

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[1] [Mr. Seward was apparently not aware that these specimens had been collected (by Mr. Tait) from Jurassic strata *in situ*, a circumstance which adds weight to his following conclusions.—*A. H.*]

IV. Concluding Considerations.

The question of the true relations of the pitchstone of the Sgùrr has been discussed above in the light of such direct evidence as can be adduced. Other considerations, which may legitimately find a place here, arise when we regard the petrographical characters of the pitchstone and its probable place in the long sequence of British Tertiary igneous rocks.

The pitchstone itself has been described by Prof. Judd,[1] and analysed by Mr. Barker North. The analysis, reproduced in column I (below), proves that it is of subacid composition, and not essentially different from some of the Arran rocks. Pitchstones, rhyolitic, trachytic, and dacitic, referred to the Tertiary suite, occur as sills and dykes in Arran, Ardnamurchan, Eigg, Rum, and Skye, and in Counties Down and Donegal. There are also, in Arran, Eigg, and elsewhere, rocks of the same general characters but devitrified, and these are often intimately associated with the glassy varieties. Most of these occurrences are of small dimensions, but the sheet of devitrified pitchstone which forms the upper parts of Ashval and Sgùrr-nan-Gillean, in the Isle of Rum, exceeds in extent and thickness the pitchstone of the Sgùrr of Eigg. This Rum occurrence and one or two others belong to an earlier epoch of the hypabyssal phase; but all the rest are to be assigned to the very latest manifestations of igneous action in the British area. Wherever evidence is obtainable, these rocks are clearly intrusive.

	I.	II.	III.
SiO_2	65·81	63·34	66·03
Al_2O_3	14·01	...	12·55
Fe_2O_3	4·43	...	2·75
MgO	0·89	...	2·33
CaO	2·01	...	2·80
Na_2O	4·15	4·56	5·02
K_2O	6·08	4·50	4·13
Loss on ignition	2·70	...	4·20
	100·08		99·81

I. Porphyritic pitchstone, Sgùrr of Eigg: anal. Barker North, Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 379.

II. The same: partial analysis by Dr. W. Pollard.

III. Pitchstone, Tormore, Arran: anal. M. M. Tait, Bryce's 'Geology of Arran & Clydesdale' 3rd ed. (1865) p. 185.

The only case (omitting the Sgùrr of Eigg) in which this statement is not one of common agreement is that of Beinn Hiant in Ardnamurchan. The sheets of andesite and pitchstone which form that hill were regarded by Prof. Judd[2] as lava-flows, but Sir Archibald Geikie[3] has given good reasons for treating them as intrusive sills. The rock of the Sgùrr of Eigg, then, if an intrusive

[1] Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 380.

[2] *Ibid.* pp. 373–76.

[3] Trans. Roy. Soc. Edin. vol. xxxv (1888–90) pp. 118–19.

sheet, falls naturally into its place as a member of this group of intrusions, with which it has much in common. It further resembles the rest in the absence of steam-vesicles, a negative character which is not easily reconcilable with a glassy subaërial lava containing 2·7 per cent. of water. The irregularly undulating lower surface of the sheet also agrees with what is seen in many other members of the group which have assumed the stratiform habit. Indeed, it is very noticeable that the remarkable regularity observable in the basic sills of the region is rarely realized in the sheet-formed intrusions of more acid rocks.

The history of Tertiary igneous activity within the British area is, in its main divisions, a simple one. Setting aside the Sgùrr of Eigg, all the superficial volcanic manifestations, including the general outpouring of basic lavas and the more varied local outbursts at certain centres, were comprised within the earlier portion of the time. Later, the various groups of plutonic rocks—ultrabasic, basic, and acid—were intruded in order. Later still came the long succession of minor intrusions—sills and dykes—embracing numerous episodes, and doubtless representing a prolonged lapse of time. This general sequence of events in a complete cycle of igneous activity may be paralleled in various other regions. If the pitchstone of the Sgùrr of Eigg, belonging to the very latest epoch, is held to represent a belated volcanic outpouring, it must stand as a unique exception. Without setting up such considerations against direct evidence, we may welcome any well-grounded interpretation which brings the apparent anomaly into harmony with what seems to be a significant law.

One other point remains to be noticed in conclusion. The picture of the pitchstone-lava of the Sgùrr filling an old river-valley has excited general interest, chiefly as affording a striking monument of erosion. Now, the unequivocal proof of enormous erosion which meets the eye in every part of the Inner Hebrides is, on any reading of the phenomena, sufficiently impressive. Such sections as that of Beinn Mòr in Mull prove that, in some parts of the region at least, the alternations of basalts and dolerites have had an aggregate thickness of more than 3000 feet. Assuming, as is generally supposed, that sill-intrusions can be formed only under a considerable cover, the alternating succession must have been capped originally by some thickness of basalt-lavas free from sills, adding perhaps another thousand feet to the total. Comparing this with the existing relief and geological constitution of the isles, we see reason to allow extraordinary activity to the agents of erosion in this region. In some parts, as on Rum and over about one-half of Skye, the great thickness of basic rocks has been entirely removed, and the plutonic masses, which in a general sense underlay them, have been left standing out to heights of 2500 and 3000 feet. This indicates a vertical erosion amounting, in some places and over considerable areas, to perhaps 5000 feet. The actual removal of material has, however, been vastly greater

than that implied in this laying bare of the deeper rocks. In the precipitous sea-cliffs of Mull, Eigg, Canna, and the northern and western coasts of Skye, the truncated edges of the basalts and dolerites are exposed in sections 500 to 900 feet high. It is clear that the horizontal extension of the rocks has once been far wider than the present land-surface; and it is highly probable that the stratiform basic rocks of the several islands, now divided by soundings of 50 to 100 fathoms, are merely relics of one continuous tract. Faulting and differential subsidence have played an important part in producing the actual map of these western isles; but we know of no such movements later than a somewhat early epoch in the phase of minor intrusions, and a truly surprising work must be credited to the co-operation of subaërial and marine erosion, perhaps with some assistance from ice.[1] The basaltic lavas being of subaërial outpouring, their destruction must have begun as soon as they were formed; and the upper flows, without the protection of dolerite-sills, might be destroyed with comparative rapidity; but it is none the less manifest that by far the greater part of the erosion was accomplished subsequently. It was not only later than the sills, but later than all the basic dykes, which occur up to the highest summits: that is, it was subsequent to the cessation of igneous activity. On the other hand, it was practically complete, except in the higher mountains and possibly in some of the sounds, before the advent of Glacial conditions. Between these limits we have to find scope for the agents of erosion to accomplish their work; and, even with all allowance for the land standing then at a higher elevation than now above sea-level, the results are not a little surprising.

Bearing these considerations in mind, we see that the lava-flow hypothesis of the Sgùrr of Eigg confronts us with very great difficulties. It takes this small area quite out of relation with the rest of the region, and demands for it a chronology irreconcilable with that deduced elsewhere. The valley-bottom, now the highest ground on the island, appears thus as a relic of a vanished topography, of which we have no other trace. The carving out of such a valley, down to within 600 feet of the base of the basalts, implies a remarkable amount of erosion, which must be compressed within extremely narrow time-limits. For, by the same reasoning as before, it must have been in the main subsequent to the intrusion of the dolerite-sills and dykes, and, *ex hypothesi*, it was completed prior to the pitchstone-epoch. The greater part of the work must in this case have been accomplished in a small fraction of the time covered by the phase of minor intrusions. Nor can we evade the difficulty by supposing the pitchstone of the Sgùrr to represent an isolated episode, of much later date than all other igneous rocks in the region; for the evidence of immense erosion subsequent to

[1] The soundings on the Admiralty-Charts indicate well-marked basins in numerous places. Good examples occur in the Sounds of Raasay and Applecross, on either side of Raasay and Rona.

A. S. Reid, Photo. *Bemrose, Collo.*

THE SGÙRR OF EIGG.

A. S. Reid, Photo. *Bemrose, Collo.*

BIDEIN BOIDHEACH (ISLE OF EIGG).

that date is as clear here as elsewhere. It includes the removal of the greater part of the then existing mass of Eigg, leaving the valley exalted to a summit-ridge. It includes perhaps the separation of this island from Oigh-sgeir (Hyskeir), 18 miles to the west, now divided by a sea 40 to 50 fathoms deep. On the lava-flow hypothesis it certainly includes the cutting back of the coast of Eigg for miles, until the cliffs truncated the valley at an altitude of more than 500 feet above the present sea-level.[1] If the pitchstone of the Sgùrr of Eigg is an intrusive sheet, this dilemma vanishes with the other difficulties which have been pointed out above; and, in its erosion as in other respects, Eigg is brought into correlation with other parts of the region to which it belongs.

EXPLANATION OF PLATES III & IV.

Plate III.

The Sgùrr of Eigg, from a photograph by Mr. A. S. Reid. See key, fig. 3, p. 46.

Plate IV.

Bidein Boidheach, Isle of Eigg, from a photograph by Mr. A. S. Reid. See key, fig. 4, p. 53.

Discussion.

The President said he was sure that, from the sentimental point of view, the feeling of the Fellows was one of regret that doubts should be cast upon an explanation of phenomena which had long been dear to all geologists.

Sir Archibald Geikie said that, owing to the lateness of the hour, it was not possible for him to criticize the paper in detail, but he hoped to have an opportunity of doing so after it had been published. He would have been glad to go over the ground with the Author and discuss the points in dispute on the spot, but he only heard of the Author's views late in the summer, when it was no longer possible for him to return to the Western Isles. None of the points raised in the paper seemed to the speaker to be incapable of explanation in accordance with the interpretation of the Scuir which he had himself proposed many years ago. It appeared to him that the Author had very greatly exaggerated the proportion of sills among the plateau-basalts. It was difficult to conceive the physical possibility of these basalts being invaded by such a multitude of intrusive sheets, and yet that they should show so little visible sign of disturbance. That there were true sills in the district was well known, but the Author seemed to have somehow come to the conclusion that every columnar sheet must be a sill.

[1] Reckoned from the sea-level at the epoch of the great erosion, the altitude would doubtless be considerably greater.

The speaker, on the contrary, believed that a large proportion of these columnar sheets were as true lava-flows as the amygdaloidal basalts with which they so regularly and abundantly alternated.

The same tendency to see sills everywhere had apparently led the Author to frame his theory of the Scuir. Sills were commonly supposed to have forced their way along the planes of least resistance, as for instance between the bedding; but the pitchstone of the Scuir, instead of inserting itself between the nearly-level sheets of basalt, had filled up a hollow in these rocks, which, if not there before the intrusion, must have been ploughed out by the intrusive mass—an operation which would require a good deal of explanation. But that this hollow did exist before the advent of the pitchstone seemed to the speaker to be demonstrated by the section shown in the vertical cliff at the western end of the ridge. The pitchstone was there distinctly seen resting in the hollow, the bottom of which was occupied by a mass of coarse shingle or conglomerate. The hollow and the detrital material filling it had a close parallel in a remarkable section, which the speaker had described from the neighbouring island of Canna, where a gully with vertical walls had, during the volcanic period, been eroded out of the bedded basalts and had been buried under succeeding outflows. The Author asserted that the mass at the western end of the Scuir was a volcanic agglomerate, but he adduced no evidence in support of that assertion. Any ordinary volcanic neck would have descended vertically through the rocks below, but the basalts underlie the Scuir conglomerate, and preserve their unbroken regularity along the face of the cliff. In like manner, in Canna the gully referred to shows its shingle lying upon a flat unbroken pavement of basalt. It is manifestly the buried gorge of a watercourse, and the speaker held that the same explanation applied to the similar structure at the Scuir of Eigg.

The supposition that the pitchstone is a sill raises some insuperable difficulties. The rock consists not of one continuous mass, but of a series of layers or beds, superposed one upon the other. According to the Author, the original glassy pitchstone has been invaded by a number of sheets of pale felsite. He offered, however, no explanation of how these sheets could be supposed to have split up the original solid sill by insinuating themselves, not between the columns, but across them, in a direction along which it might have been supposed that they would meet the greatest obstacle to their progress. These felsites resemble the brecciated bottom of the main pitchstone, like which they were regarded by the speaker as parts of a succession of flows which filled up a long and wide hollow worn by erosion out of the plateau-basalts.

The Author of the paper seemed disposed to minimize the amount of denudation during the volcanic period. The speaker, on the other hand, believed that it must have been large, and he referred in proof to the evidence of erosion and widespread accumulation of waterworn shingle to be seen in Canna and elsewhere. In conclusion, he submitted that, while he was ready to abandon his published conclusions when they were shown to be erroneous, much

better evidence must be adduced against them than had been laid before the Society that evening.

The Author, in acknowledging Sir Archibald Geikie's criticisms, echoed his regret that a joint visit to the locality had not been found practicable.

He was not to be understood as denying that the ordinary processes of erosion went on during the basalt-period. The fluviatile conglomerates intercalated in the succession were evidence of contemporaneous erosion, although it is probable that these derived much of their material from the volcanic agglomerates rather than from the lavas.

The intrusive nature of the dolerites had been deduced from the various direct criteria mentioned in the paper, the generalization that the vertical jointing is a characteristic of this intrusive group being a consequent conclusion.

5. *The* COAST-LEDGES *in the* SOUTH-WEST *of the* CAPE COLONY. By Prof. ERNEST H. L. SCHWARZ, A.R.C.S., F.G.S., Rhodes University College, Grahamstown, South Africa. (Read November 8th, 1905.)

THE subject of continental ledges has recently been brought into prominence in Europe and America by Prof. Hull, Prof. J. W. Spencer, and others; it is one in which attention to details has revealed many surprising results, which have modified our conception of the relation of land to sea, with the host of cognate problems. I offer the present contribution on the same subject, with the object of further emphasizing the importance of such investigations; for in South Africa we have the same set of phenomena, although we are able to study the movement in quite a different phase from that in which we find it in Europe and along the eastern coast of North America.

The writings of the above-mentioned authors, together with those of Prof. J. Geikie, Prof. A. Issel, and Prof. W. C. Brögger, have made the subject so familiar of recent years, that I need not enter into a discussion of the general principles involved. Suffice it to say that, as the land rises, there are set-backs which allow the wash of the breakers to cut level plateaux of marine denudation; when a maximum elevation is reached, the land sinks and these ledges or fringing plateaux can be traced in the soundings set down on charts of the coast. In Europe, the first to draw attention to the subject were Godwin-Austen [1] and De la Beche [2]; and since then, the surveys for the submarine cables have furnished the information for a very complete statement of the occurrence in the North Atlantic.

In the following pages I will set forth what evidence we have along the southern coast of Cape Colony for the existence of these fringing plateaux, and then at the end compare them with the European and American ledges.

The most striking of the coastal plateaux is that rising from 600 to 800 feet above sea-level, which extends from Caledon to Port Elizabeth. In the west it is cut in Bokkeveld (Devonian) Slates, with here and there inliers of sandstone that rise from the plain in the form of hills. To the eye of a casual traveller there is very little evidence of a plain in this country; for there is a perfect labyrinth of steep-sided gorges, which cut the land into narrow ridges, or ruggens, as they are called in Dutch. If the observer, however, climbs on to an eminence and looks across the valleys, he notices that all the ridge-tops are cut to a level which slopes gently

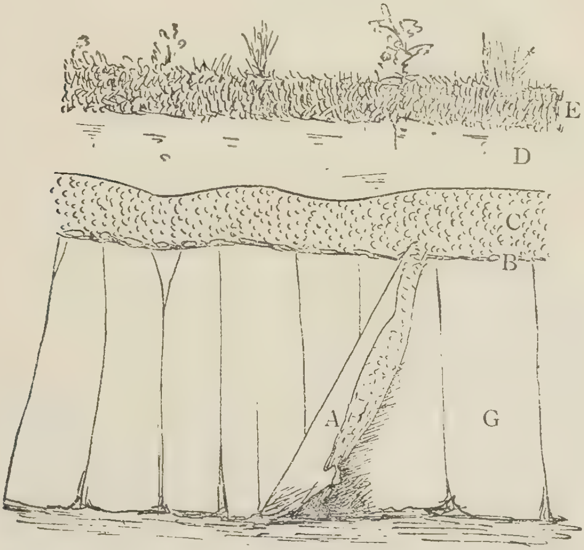
[1] 'The Valley of the English Channel' Quart. Journ. Geol. Soc. vol. vi (1849) p. 69.

[2] 'Geological Observer' 2nd ed. (1853) pp. 90–91.

to the sea. The same thing is noticed in travelling: for the road that has to be followed, in order to get from one place to another, usually describes an immense circuit, but all on the level; whereas to go straight would necessitate climbing up and down a succession of very steep hills.

The plain, or the tops of the ridges which now represent the plain, in the western part, is in places covered with surface-deposits. Near the mountains there are heaps of great, rounded, water-worn boulders, often cemented together in a siliceous matrix: farther away we find gravels with pebbles of all sizes, either loose, or cemented by silica or compounds of iron; still farther away there are sandy clays, which, according to circumstances, harden on the surface to an ironstone, or to a siliceous rock—burrstone, or freshwater quartzite.

Fig. 1.—*Ironstone-gravel forming beneath the sour soil of the Uplands plateau, seen in a railway-cutting south of George Town.*



A = Quartz-vein traversing the rotten granite, G; B = layer of subangular fragments of vein-quartz; C = sand, cemented into a granular mass by hydrated oxides of iron; D = grey sandy soil; E = humus.

[Compare the description of ironstone found beneath the sandy soil of Wolmer Forest, in Gilbert White's 'Natural History of Selborne' letter iv. 1st series.]

To the east—or, to be precise, from George Town to Port Elizabeth—the plateau-form becomes much more prominent: the rock out of

which it is cut is mostly Table-Mountain Sandstone or granite, and both of these are far more resistant to the action of weathering agencies than the clay-slates of the Devonian Bokkeveld Series. Very deep gorges do traverse the plateau here, but they run straight

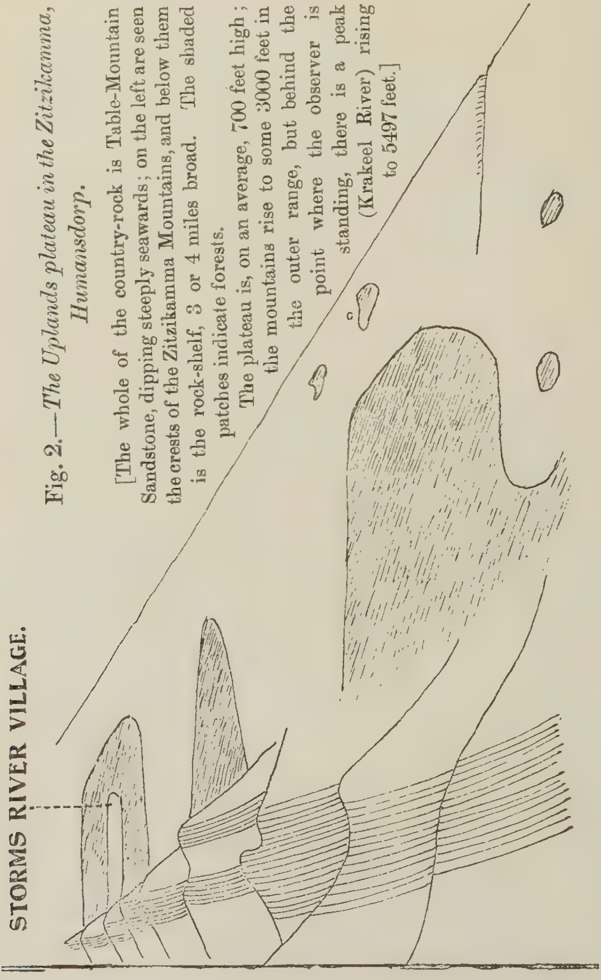


Fig. 2.—*The Uplands plateau in the Zitzikamma, Humansdorp.*

[The whole of the country-rock is Table-Mountain Sandstone, dipping steeply seawards; on the left are seen the crests of the Zitzikamma Mountains, and below them is the rock-shelf, 3 or 4 miles broad. The shaded patches indicate forests.

The plateau is, on an average, 700 feet high; the mountains rise to some 3000 feet in the outer range, but behind the point where the observer is standing, there is a peak (Krakeel River) rising to 5497 feet.]

down to the sea from the mountains, and such water as falls upon the plateau sinks in to fertilize the soil, and drains away through the cracks and joints of the rock.

The character of the vegetation is very different on the plateau east and west of George Town. In the ruggens-country there is very

little soil on the hills, the bare rock in most cases showing through. The bushes were originally the woody Karroo-bushes, which force their roots down in the crevices formed by surface-expansion and contraction, and the necessary soil exists only in these small fissures ; a useless, imported, rhenoster-bush, however, is displacing the natural vegetation, to the great detriment of the country. In the east, the vegetation grows on a thick, sandy soil, and consists of grasses, sedge-like plants, proteas, heaths, and many of the beautiful Cape-iris family. The ruggens-veld is sweet veld, but the heath-country is sour.

Beneath the sand on the sour veld there commonly forms an ironstone, due to the action of water dissolving out iron-compounds from the rocks, and this shuts off the roots of the plants from the substratum of rock ; where this is granite, which contains the finest mineral foods for plants, such as lime, phosphates, and potash, the surface-vegetation is as poor as that on the Table-Mountain Sandstone, which is made up of pure silica with scarcely a trace of argillaceous matter. If, by any chance, the soil is removed from off the ironstone-gravel, the latter hardens on exposure to a massive bank of ironstone ; it is then what is sometimes called laterite, although there is no alumina to render the application of the term strictly correct.

The deposits on this coastal plateau have given rise to much controversy, and their nature seemed so essentially that of river-deposits, that for a long time the plain was thought to be a base-level of river-erosion. In Komgha, in the extreme east of the Colony, some of the freshwater quartzite was found to contain seeds of *Chara*, thus pointing to the fact that the deposit was formed in fresh water. But it does not necessarily follow in this particular case, because the deposit on the plain is evidently freshwater, that consequently the plain itself must have been cut by river-action ; for Mr. W. Anderson [1] has recorded *Chara*-seeds in a deposit on the shores of a lagoon on the Zululand coast, which lies evidently on a plain of marine denudation that has just emerged from the surface of the ocean.

In Caledon and Swellendam, where the width of the plateau is some 15 or 20 miles, and the seaward end shut off by a series of outstanding hills, the problem is complicated ; but, standing on the top of a peak of the Zitzikamma Mountains, and surveying the ledge at one's feet, which is only some 3 or 4 miles broad, it seems impossible that rivers coursing down from the mountains could, in so short a distance, acquire that sluggishness and lack of velocity which would be required to enable them to cut their channels sideways, and level the rugged country. There is no possibility of invoking a different cause for the levelling in the two places, for the same plateau is continuous, right away from the western end of Caledon to the town of Port Elizabeth ; the same level, the same gradient of fall from the mountains to the sea, the same general

[1] 2nd Rep. Geol. Surv. Natal & Zululand, London, 1904, p. 51.

nature of the deposits, are found on the ledge from east to west, and an explanation of its formation in one part must hold good for the whole. As I think that we have evidence for ruling out the possibility of river-erosion as a cause for the cutting of the ledge in the Zitzikamma, so must we abandon the theory of the ruggens-plateau being a peneplain.

Another plateau, commencing on the east of Port Elizabeth, and beginning at the sea-front with an elevation of some 150 to 200 feet, is covered with undoubted marine shingle: it rises to 400 feet, and at the base of the next plateau it is 460 feet above tide-level. All over the plain there are these coarse boulder-beds, sometimes associated with shell-deposits characterized by a large *Pectunculus*. Most of the shells are of species living on the coast at the present day, but the larger forms are now found only along the Natal coast. On the top of the plateau and in the surface-gravels, is a circular depression called the Groot Pan or Zwartkop's Saltpan; it annually fills with rain-water, which on evaporation throws down salt of great purity, 100,000 bushels being extracted yearly. I do not think we can say that this salt-pan, by itself, is an argument in favour of the marine origin of the plateau; though the simplest explanation of the occurrence would be that the salt results from the leaching-out of the evaporated sea-water that was held up in between the boulders as the beach rose above sea-level. The enormous amount held up in the pan is the puzzling feature; for the apparently-inexhaustible supply would seem to necessitate a soil impregnated with salt in the neighbourhood, yet the dense bush of prickly plants, aloes, euphorbias, mimosas, scutias, etc., grows up almost to the water's edge. The saltpans in Bredasdorp and at Bethelsdorp, nearly at sea-level, seem also to receive an adequate explanation on the theory that they are the result of sea-water evaporated and impregnating the neighbouring soil; but one can hardly so explain the saltpans, at Prieska, for instance, which are hundreds of miles away from the coast.

In stating that there was no break from east to west in the Uplands plateau, I spoke of the land as we have reconstructed it; for nowadays there are many gaps, caused by the inclusion of immense deposits of loose Cretaceous rocks, which have readily yielded to the impetuous torrents that coursed over the plateau. These deposits, which we term Uitenhage Beds, are made up of a basement-series of gravels known as the Enon Conglomerate, and of sands, clays, and marls, characterized by *Tæniopteris* and *Cladophlebis denticulata*. They once covered a very much greater extent than they do at present, but after their deposition some extraordinary cross-folding took place, which let them down in hollows in the older rocks upon which they had been lying; the basins in which they are now found are bounded by steep walls, sometimes a buried fault-face, sometimes a very steep fold, and are entirely closed. During

the levelling process all trace of the Cretaceous deposits was removed, except in these hollows, where the unbroken rim of the more consolidated, older rocks protected them. When the plateau was raised, these Uitenhage Beds exhibited the same levelled surface as the rest of the rocks, and recent gravels were deposited upon them; but the enormous powers of downward erosion which the rivers now acquired, attacked these loosely-made rocks and carried them away to the sea: hence there are wide, open basins on the plateau wherever the Cretaceous deposits occur.

As regards the recent deposits found on many of the ridges of the Ruggens, I think that the greater part of them are formed *in situ*—that is to say, before the country was cut up into these ridges, there were extensive plateaux covered with thick sandy soil, such as we now see is the case to the east in Knysna, on the same plateau, though on a harder substratum of rock. Water percolating through this soil would form the ironstone-gravel by cementing the sand-grains with hydrated iron compounds, and the surface-quartzite could be formed in the same way by the deposition of silica.

In Uniondale I have seen the process of formation of the burr-stone going on. The plateau there has been cut, very thick deposits of clayey sand have been piled upon it, and the gradual hardening upwards, till the surface is glassy quartzite, can be studied.[1] Gravel does exist on the ridges, and this cannot, except within very narrow limits, be explained in a similar manner: when a hard reef projects above the general level of the plateau (for instance, a quartz-vein through granite), fragments, apparently waterworn, of the same material are found in the loose sandy soil in the neighbourhood; but they have never been noticed actually to form gravelly deposits (see fig. 1, p. 71). Yet gravel is not formed by river-action alone: beaches are as common as river-gravels; and Godwin-Austen as long ago as 1849 recorded shingle on the English platform at from 80 to 100 fathoms below the surface of the water.

Behind the mountains, we find the remains of plateaux cut in various rock-systems, resembling the Uplands plateau in certain features, only they are of considerably greater elevation. They are covered with surface-quartzite, ironstone-gravel, and shingle, exactly as in the coast-plateau. After studying both, I am unable to distinguish the two deposits one from the other, and yet I see as complete evidence for ruling out the action of waves from the explanation of these inland plateaux, as I see for abandoning the action of running water in explaining the formation of the coast-ledge. We are not directly concerned with these inland plateaux in the present paper; they were described in the memoir on the 'High-Level Gravels of the Cape, &c.' referred to above.

[1] See photograph in 'High-Level Gravels of the Cape, &c.' Trans. Phil. Soc S. A. vol. xv (1904) pt. 2, pl. iii.

In Bredasdorp and Riversdale there is an immense accumulation of blown sand on the coast. The dunes rise to 600 and 800 feet above sea-level, and rest upon shelves of varying heights. In Bredasdorp, near Cape Infanta, the base is seen some 100 feet above sea-level, and is composed of hard quartzites; to the west, however, the base goes below sea-level.[1] In Riversdale the base seems to have been generally only a few feet above sea-level, and the strata consist of exactly the same rocks as those which go to form the ruggens-country behind—namely, Bokkeveld Slates.

Sand on the southern coast of South Africa is shell-sand. The waves throw up the valves of dead molluscs, which get rolled up and down by the ebb and flow of the tide, and finally are broken into such small fragments that the wind can carry them away. This sand, then, masses up in these great dunes, sections of which show very clearly that the whole of the deposit is wind-borne; for the false bedding is so abrupt and striking, that no streams or currents could have produced such marked effects. The angular fragments of shells sometimes break down to a powdery, chalky mass; but as a rule the sand remains just as it was, piled up without any alteration except on the surface. Where rain-water can penetrate and come to rest, there is a process of solution and redeposition of lime which consolidates the sand into a rock hard enough to be used for building-purposes.

The fossils found in the sand-dunes are all of recent age, the commonest being the snail, *Cyclostoma*. In the two districts with which we are immediately concerned, bones of the elephant, rhinoceros, eland, sable antelope, and large carnivores have been found—all species which have, since the coming of the white man, disappeared from this neighbourhood.

In Riversdale and Bredasdorp the level of the top of the sand-dunes is very nearly the same as that of the plateau behind; there has been a little erosion at the junction, and a well-watered valley extends at the inner foot of the dunes; the rise, however, from the old high-level plateau to the dune-country is very slight. In George and Knysna there is a very similar accumulation of sand; only here the original bluff of the plateau, rising steeply in precipices from sea-level to 600 feet, is bare, and between it and the sand-dunes there is a level tract of low country occupied by the far-famed Knysna Lakes. I should be inclined to atttribute the difference between the two tracts to the direction of the prevailing winds. In Riversdale and Bredasdorp this would have been slanting with respect to the land, whereas in Knysna the winds blew straight from the sea. In the latter case the steep cliffs would have produced a back-eddy which swept the sand away from their base, whereas in the former the sand could be piled up against them. Whatever be the explanation, the difference does exist.

[1] See Rogers & Schwarz, 'Notes on the Recent Limestones on Parts of the South & West Coasts of Cape Colony' Trans. Phil. Soc. S. A. vol. x (1897–98) p. 427.

There is a further and more important difference in the Knysna dune-area—namely, the base upon which the sand rests is below sea-level. It seems at first sight strange that so loose a material as the sand-rock should remain consolidated when it is sunk beneath the water, but we have had ample proof that it does. Near Danger Point, the bluffs of wind-deposited sand dip steeply seawards, and pass beneath the tide-level; and at Cape Infanta there is a great cave excavated in the sand-rock, with an old beach forming the roof. Dr. J. C. Branner mentions that, at Fernando de Noronha, wind-bedded sand occurs below tide-level.[1] Off the George coast there are several ledges, separated from each other by steps of a couple of feet or so, made of consolidated sand-rock, the uppermost of which is rarely covered by the sea, so that the spray evaporates in the pools and yields salt; but the lower ledges are covered and uncovered at each ebb and flow of the tide, and the terrific surge of the breakers beats upon them incessantly. The surface of the ledges is exceedingly rough, and has been formed by the rock cracking along intersecting joints; these become filled in with lime and form walls round the enclosed blocks. When exposed to the waves the softer interiors become eaten away, leaving the walls outstanding, and where two or more cracks intersect a little pinnacle is produced. Sometimes the cracks are very scanty and the included blocks correspondingly large, so that wide, shallow pools are formed, with low enclosing ridges; these are densely crowded with calcareous algæ, worms, and other lime-secreting organisms, and thus the surface is further strengthened by a thick deposit of calcareous matter.

The question arises: if the sand-rock can be so hardened, might these ledges not be the ordinary shore-sand hardened *in situ*, by a process similar to that which, as Dr. Branner (in the memoir just mentioned) maintains, built up the stone-reefs of Brazil? At the western end of the George sand-belt the limestone-ledges do not appear above tide-level; but they exist below it, as shown by the numerous fragments that are thrown up along the shore, yet there is no tendency for the beach-sand to form similar ledges. As certain proof exists in the caves of Cape Infanta that the sand-rock has at one time gone beneath sea-level, and as all sections along the coast where the ledges occur are favourable to the view that the sand-rock does pass under the sea, we can accept with confidence the statement that these limestone-ledges are formed of wind-bedded sand hardened by sea-water.

There is a very simple explanation of this hardening. When the tide recedes, it leaves behind it in the pools and hollows of the ledges a certain amount of sea-water, which contains carbonate of lime in solution, in virtue of the carbonic acid which it holds; when the water is exposed in shallow sheets to the heat of the sun, the gas is driven off and the lime deposited, the process thus necessitating, in the first place, a more or less solid ground for the

[1] Bull. Mus. Comp. Zool. Harvard, vol. xliv (1904) p. 229.

water to come to rest on, and explaining at the same time how it is that loose sand is not similarly consolidated. At Port Elizabeth there is a beach-deposit cemented into what is known in South America as a stone-reef; this may have been formed *in situ*, for the sea-water, when the tide ebbs, would be retained under the rounded stones, and carbonate of lime deposited as the water became heated.

At Hermanuspetrusfontein, on the Caledon coast, there is a well-marked surf-cut ledge about 50 feet above sea-level,[1] which would correspond to the ledge of rock underlying the sand-dunes at Cape Infanta; while farther out, at Danger Point, the sand-dunes rest upon a ledge that has sunk beneath the sea. At Agulhas Point the ledge is just at sea-level round the lighthouse, but it is very narrow here. Most of these places along the coast are so inaccessible, and the problems with which we are concerned in this paper have been so recently advanced, that the exact heights of any one of these ledges has not been determined with any accuracy; but the point which I wish to bring out is that there are more or less extensive ledges, admittedly surf-cut, at various levels above and below tide-mark along this part of the coast.

The Cape Peninsula extends from Cape Point to Table Bay, and is a precipitous mass of sandstone resting upon a basement of pre-Cape rocks and granite. It is separated from the mainland by a wide tract of low-lying country covered with drifting sand, known as the Cape Flats. The sand is gradually being fixed by plantations of trees, and quickgrass and other creeping plants, but much of it is still pure, loose sand. If one bores through the sand one meets first with a layer of ironstone-gravel (the so-called laterite), and then a thickness of clayey material derived from the weathering of the Malmesbury Beds, and finally the hard blue clay-slate itself. It is very difficult to say at what level the true rock-shelf exists under the sand, owing to the want of available evidence; but I think that the ironstone may be said to rest upon the original surface. This, then, is commonly found near sea-level, taking an average, sometimes going below, sometimes occurring above that datum. Geologists have always been very chary in expressing an opinion as to the nature of the cause which cut this level flat; but I see no reason for propounding a separate explanation for this particular plain, when we have similar ones, clearly surf-cut, all along the coast to the east. The laterite-, gravel-, and lignite-deposits seem to point to these having been formed on land, but the shingle and tree-trunks may have been rolled to their places by the sea, and the laterite can and does form *in situ* beneath any sandy soil. Therefore I see no hindrance, in the nature of the deposits found in the Cape Flats, to the acceptance of the agency of sea-waves in cutting the original plain. There need not here be any question of a strict mathematical plane: for we

[1] A. W. Rogers, 'The Geology of Cape Colony' 1905, p. 380.

know that, at many places where there are shallow lakes and lagoons, there are hollows in the rock-shelf; but these are distributed so irregularly that they can offer no support to the theory that running water was the cause of the cutting of the Flats.

Near Cape Point there is a raised beach about 100 feet above sea-level; and Mr. A. W. Rogers describes some very well-marked shingle-deposits on the same level on the western coast, near the Van Rhyn's-Dorp area.[1] At the base is a conglomerate strongly impregnated with iron-oxide; the pebbles are of all sizes up to a foot in diameter, and consist of a considerable variety of rocks—sandstones, quartzites, schistose quartzites, granites, quartz-porphyries, vein-quartz, and slates. Above this layer come more or less ferruginous sandstones, which are in places silicified. In Bamboes Bay, 3 miles south of Strandfontein, the ferruginous conglomerate passes upwards into sandstones, and these again into calcareous beach-deposits containing shells of species still living on the coast. The country behind the coast, at a distance of 4 miles from it, lies between 500 and 600 feet above sea-level. It would be very interesting to follow the surf-cut levels northwards. At Port Elizabeth and Uitenhage, the beach-deposits and shell-banks lie on a shelf about 200 feet above sea-level; but this slopes gradually up to 600 feet, and I am inclined to reckon the 100-foot level as a substage of the Uplands plateau.

We have, then, a plateau 700 feet above sea-level, and one at about sea-level. I will now discuss one at considerable depths below: this is the plateau the edge of which is known as the Agulhas Bank.

Soundings off the south-western corner of South Africa soon get into depths of 40 to 50 fathoms; and then, out to sea, there is a gradual slope of the sea-bottom to 90 or 100 fathoms. The marine charts seem to express a succession of ledges rather than one continuous slope, one of the plateaux being at 45 to 60 fathoms, another at 70 to 80 fathoms, and an outer one at 90 to 100. Close in-shore, along the Zitzikamma, is a narrow shelf at 30 fathoms, with a sharp drop off the edge to 50 fathoms. At one place on the plateau there is a sounding of 134 fathoms which may be simply an embayment, but also it may be a rock-channel, which once carried the waters of the Breede River out to sea at this point, nearly 100 miles from its present mouth. The effect of a rise of the continent of 600 feet would prolong the land some 150 miles to the south, with the apex of the point shifted somewhat to the east of where it now lies. We should then have two well-marked plateaux: one at 600 feet, more or less, and one at 1300 feet, more or less, above sea-level, besides the one at or near sea-level. As it is, the remnants of one are found to exist at about 1500 feet,

[1] 'Geological Survey of Piquetberg, Clanwilliam, & Van Rhyn's Dorp' Ann. Rep. Geol. Comm. 1903 (Cape Town, 1904) pp. 161–62.

and this I will shortly describe. Thus our sub-continent seems to have been subject to lifts of 600 to 700 feet or so, with smaller intermediary halts and set-backs.

Shell-sand, green sand, mud, and boulders have been dredged off the surface of this submarine plateau. For some years now the s.s. *Pieter Faure*, the Government trawler, has been making investigations over this area with regard to the supply of fish; and when the records are worked up we shall have, perhaps, some more definite data upon which to go. Some large quartzite-boulders, dredged 40 miles off Mossel Bay, showed that there at least land must have been at one time. The occurrence of this plateau, corresponding so closely with that which surrounds the eastern shores of America and the western shores of Europe, led me, in a recent paper, to suggest that it was caused by the bending of the edge of the continent seawards: owing to the carrying-away of material from the interior by denudation, and consequent relief of weight, and the deposition of this material as sediment off the shores, and consequent weighting of this area. If, however, we consider the coast-ledges to be plains of marine denudation, this explanation is unnecessary, as we have evidence of block-uplift of the whole continent, and not of bending of only small portions of it.

Whether there are plateaux below the Agulhas Bank, must remain problematical, until more extensive exploration and soundings have been made. The evidence, so far as we now can judge, goes to suggest that the ground off the Bank belongs to the absolute base-level of erosion—that level beyond and below which the action of running water was never effective, taking the continent as the unit which it now is. In former ages there may have been elevations and depressions along the coast which had an absolute base-level different from that which we assign to the movement that we see going on at the present time: an elevation, for instance, that may have connected the island of Madagascar with the mainland, or a depression that permitted the deposition of the Cretaceous marine rocks or the Karroo Beds. These periods are, however, remote, and our powers of reconstructing the physical conditions of the continent are faulty, from the want of data upon which to go; consequently, we are not likely to have more than one absolute base-level at any one place to deal with, and the confusion of speaking of several absolute base-levels will be avoided. There is a change in the fauna exhibited in the 200-foot shell-deposits at Port Elizabeth and Uitenhage; and if the 2500-foot plateau had remains of animal life upon it, they would indicate a further change, but there is nothing to lead one to suppose that even the highest undoubted surf-cut shelf was made in times as far back as the Tertiary.

The absolute base-level of erosion, as I conceive it, refers simply and solely to the movements of continents as they now are, and has nothing whatever to do

with the question of the permanence of the continental outlines in past ages: that is a question which may be decided one way or another, without affecting the absolute base-level. I have introduced the expression because I wish to imply that continents are in a state of motion, upwards or downwards, and that the absolute base-level represents the ocean-floor, including the shelf or level of erosion cut by the surf and off-shore currents that came near the water's edge when the depression of the present land-masses commenced; it is a datum from which to reckon those upward or downward movements of continents which are actually in progress.

Fig. 3.—*The De Vlugt plateau (about 1500 feet), looking north from Paarde Kop (2397 feet), across the valley of the Keurbooms River.*

[In the distance are the Long Kloof Mountains, which may be the remnants of a higher plain, 5000 to 6000 feet above sea-level; the crests are seen to run in a remarkably-level line, and the highest peak of the range (Krakeel River) has an altitude of 5500 feet. The valleys are occupied by outliers of Bokkeveld Slates folded in with the Table-Mountain Sandstone.]

In the Division of Knysna there is a complex of ridges under the mountains, formed by folded Table-Mountain Sandstone, with synclines filled in with long outliers of Bokkeveld Slates. Although the synclines pitch so that the slates are often cut out, and the sandstone-strata in places stand vertical, at others with very high dips, yet the tops of the ridges all rise to a level sky-line about 1500 to 2000 feet above sea-level. Peaks rise above this; but the evidence is satisfactory for the existence in past ages of a plateau at an altitude of about 1500 feet.

Behind the mountains are the remains of a vast plateau, at about

3500 to 4000 feet above sea-level,[1] which I have endeavoured to explain by the base-level of erosion being caused by impassable obstructions in the course of the rivers; and I still do not see my way to offer any other explanation. Had the base-level been the result of the depression of the land, we should obtain a most remarkable physiography for the western part of the Colony: there would have been a narrow fringing reef of mountains, with an immense central lagoon, like an atoll magnified. There are no traces of a 3500-foot terrace on the coast-sides of the mountains—a fact, however, which might be explained by the great denudation that takes place on the seaward side of mountain-chains; even in the dry interior the remains of this plateau are exceedingly scarce, and there would have to be some exceptional cause to allow of such being protected on the coast, did they exist. The only example of which I can think, is the summit of Table Mountain at Cape Town, 3549 feet above sea-level; but I do not wish to press this into the theory, unless many other confirmatory facts can be gathered.

I have often sat on a mountain-top, and, surveying the enormous landscape that opens out before one in the clear air of South Africa, have noticed how many of the chains of folded mountains cut a level sky-line. I have thought, too, that there might have been a vast peneplain at elevations of from 5000 to 6000 feet (see fig. 3, p. 81). Such a plain would have left only a few peaks of the folded mountain-region projecting as islands, and it would have included the top of the escarpment of the great inland plateau. This escarpment is now seen as the dolerite-capped hills that face the Great Karroo, the crests of which form the watershed between the streams running into the Orange River and those flowing southwards to the Indian Ocean.

Turning eastwards, we find the remarkably well-preserved marine plateau near Port Elizabeth and Uitenhage, to which I have already referred in discussing the marine origin of the rock-shelves. The Uplands plateau comes eastwards to Port Elizabeth, but is, I think, not quite so high above sea-level as at George or Knysna. The plateau, with the shingle and shell-deposits, is only some 150 to 200 feet high along the shore, but rises inland to 463 feet at Coerney; at this level it reaches the next step or escarpment of the higher plateau of about 1000 feet. We know too little about the country beyond this point to discuss the facts further; but, as I gazed over all this part from a peak on the Baviaan's Kloof, there appeared to be a succession of level plains, cut off by steep cliffs on the seaward side, beginning with the 4000-foot plateau and sinking gradually to the coastal one of an altitude not exceeding 150 to 200 feet.

At East London there is a remarkable succession of plateaux. The following levels along the railway-line will convey some idea of the nature of the country, if one considers that each of the

[1] 'High-Level Gravels of the Cape, &c.' Trans. S.A. Phil. Soc. vol. xv (1904) pt. 2, p. 43.

localities mentioned lies on a flat plain, or one that slopes gently towards the sea, and is terminated by an abrupt drop :—

	Feet
East London	151
Cambridge	467
Fort Jackson	1108
Berlin	1638
Blaney	1775
Sterkstroom	4406
Cyphergat	5450

In the Transkei and Pondoland the coast-shelves are very strongly marked. The main plateau is elevated about 2500 feet above sea-level, and still, in a very few cases, retains masses of surface-gravel and quartzite. One hill standing on the plateau, called Kentani Tree Hill, where there was a fierce fight in the Gaika-Galeka war, has an elevation of 2420 feet ; the peculiar freshwater quartzite, with the many-coloured clays and sands not yet consolidated by the siliceous cement, and the conical shape which the small cap of hard rock has given to the hill, have puzzled many generations of people, both black and white. Not so very long ago it was declared a diamond-pipe, and the whole white community in the district resolved itself into a syndicate to work it. The general level of the plain is some 500 feet below the level of the hard caps ; for, although the whole area is covered with grass, there is a vigorous denudation going on which is rapidly reducing the level of the country.

At Kentani village there is a cliff letting the plateau down 1000 feet, and thence by other steps to a low ridge only 50 to 100 feet above sea-level. In the neighbourhood of the St. John's River the coastal geology becomes very complicated ; but in Eastern Pondoland, where there is a simple shelf of Table-Mountain Sandstone, the subsidiary plateaux are as sharply defined now as when they rose from the water's edge.

The task of gathering together facts from levels carried out by eye-surveys, with very few points fixed in height, cannot lead to satisfactory results unless appeal can be made to more detailed work. The reason why I have brought in these eastern plateaux is to show, firstly, that plains of marine denudation do clearly exist all along this coast ; and, secondly, that the level of the plains observed at the various localities varies considerably.

Table of Coast-Shelves in the Cape Colony.

Name of Shelf.	*Western.*	*Midlands.*	*Eastern.*	*Native Territories.*
	Feet	Feet	Feet	Feet
Cyphergat	5000 to 6000 ?	5000 to 6000 ?	5450 ?	—
Sterkstroom	3500 to 4000 ?	4000 ?	4406 ?	4500 ?
Kentani	...	...	2500	2500
De Vlugt	1500	1000	1500	1500
Uplands	700	463	467	600
Bamboes Bay	50 to 100	200	157	50 to 200
Sea-level	—	—	—	—
Agulhas	−600			

In the foregoing table I have cited only the main plateaux; the figures with a query after them refer to cases where the action of marine denudation is doubtful. The highest undoubted rock-shelf is the Kentani plateau, in which the lower road through the Native Territories is laid, along which are built the villages of Kei Road, Komgha, Butterworth, Idutywa, Umtata, Flagstaff, and Bizana.

In Europe we have traces of similar terraces. The edge of the shelf supporting the British Isles is generally known as the 100-fathom line. In front of this is the great escarpment of the continent, descending steeply to 7000 or 8000 feet, sometimes precipitously; the level at the bottom is what I have called the absolute base-level of erosion. Off Scotland, the margin of the plateau lies about 600 feet below the surface; but in front of the English Channel, the soundings indicate depths of 1000 to 1200 feet. South-west of Spitsbergen lies a plateau depressed 2418 feet below sea-level, with depths immediately beyond of 8100 feet; and, farther off, the sea-floor sinks to 15,900 feet. Between Greenland and Iceland, the submerged plateau is depressed 1500 feet.

The drowned valleys of Europe open on to the sea-floor at depths of from 7000 to 9000 feet, the greatest of them being the valley of the Adour.[1] South of the Straits of Gibraltar the continental platform descends to 7200 feet, with a gradual slope probably, 'consisting of a succession of minor terraces breaking off in cliffs.'[2] In the Northern Atlantic and Arctic Ocean, littoral shells have been dredged up from depths of 8500 feet.[3] I would, therefore, make the absolute base-level of erosion at an average of 9000 feet on the eastern side of the North Atlantic. Prof. Hull, in the paper just referred to, publishes a chart of the ocean-floor off the mouth of the Congo, and shows a drowned valley opening out on to an absolute base-level of erosion at 12,600 feet, so that there is apparently a depression of the sea-floor. South of this point, I find evidence of elevation of the absolute base-level of erosion, from this great depth to only some 1000 feet; and, in passing, I should like to anticipate the conclusion of this paper by drawing attention to the nature of the river-systems north and south of the Congo: that is to say, the land-relief, in areas where the absolute base-level of erosion is very deep below tide-level, is favourable to broad valleys and permanent rivers, but where it is high the land-surface is furrowed by deep gorges and traversed by dry river-channels.

On the western side of the Atlantic, there is a corresponding continental shelf, submerged some 200 or 250 feet below the ocean-surface, with an external fringe submerged another couple of hundred feet. Off this, there is a long, gradual descent to deep water, mostly unbroken by ledges; but the Blake Plateau interrupts it in places by a shelf from 2500 to 3500 feet deep, with an average

[1] Alphonse Milne-Edwards, Bull. Soc. de Géogr. vol. iii (1882) p. 113.

[2] E. Hull, 'Sub-Oceanic River-Valleys of the West-African Continent, &c. Trans. Victoria Institute, vol. xxxii (1900) p. 148.

[3] W. C. Brögger, Norges Geol. Undersögelse, No. 31 (1900-1901) pp. 682-83.

of 2700 feet. The submarine valleys which cut through the plateaux reach to depths of 12,000 feet below sea-level. Even at these great depths there still appear to be plains, which probably were once near or above the surface of the water; for instance, south-east of New Jersey the contour-lines between 9000 and 10,500 feet are some 60 miles apart.[1] The greater depths of 20,000 feet, such as are reached in the Bartlett Deep south of Cuba, probably indicate structural depressions below the absolute base-level of erosion.

If we admit the expression absolute base-level of erosion, we have then evidence which goes to show that this surface is depressed 4000 feet more on the western shores of the North Atlantic than it is on the eastern, and that the same depression is found off the mouth of the Congo on the eastern shores of the South Atlantic, but that south of this there is a rapid elevation to within 1000 feet of ocean-level. We can, then, compare the following plateaux :—

North Atlantic, American side.	Feet	North Atlantic, European side.	Feet	South Africa.	Feet
				Kentani plateau	2500
				De Vlugt plateau	1500
				Uplands plateau	700
Sea-level	—	Sea-level	—	Sea-level	—
Coast-shelf	300	Coast-shelf	600	Agulhas plateau	600
Blake plateau	2700	Iceland shelf	1200	A. B. L. E.	1200
		A. B. L. E.	9000		
A. B. L. E.	12,000				

[A. B. L. E. = 'Absolute base-level of erosion.']

Whatever may be the objections to the term absolute base-level of erosion (and I myself can see many), it expresses some surface that must exist; and once we grasp this fact, we have a most fertile medium through which to look at the unexplained differences in the surface-conditions of continental areas. By its means we determine that Europe and America are, on the Atlantic coast, on the down-grade of the oscillatory motion which all land-masses are undergoing, and have very nearly reached bottom. South Africa, on the other hand, is on the upgrade, and probably near the top. Compare the topography of Europe and South Africa. In Europe, one finds flowing streams which have cut their beds so that adjoining stream-systems meet at the crest of the dividing-ridge: in South Africa, the stream-beds are separated by great distances of level country, the actual river-valley occupying only a narrow V-shaped gorge or channel. In Europe, the valleys are wide, great tracts of alluvium spread along the borders of the streams, and deltas form at the mouths: in South Africa, the valleys are cut almost always in rock, and at the mouths the rivers run out to sea through rock-bound gates. In Europe, when a dam is to be built, a moderate

[1] J. W. Spencer, Bull. Geol. Soc. America, vol. xiv (1903) p. 213; see also *ibid.* vol. vi (1895) p. 103.

height of wall will impound an enormous quantity of water; in South Africa, big dams are almost out of the question, because the grade of the rivers is so great that, in order to impound any quantity of water, the dam-wall requires to be built so high that the pressure on the base becomes greater than can be safely undertaken, unless at enormous cost. In Europe, the land having gone on sinking for many ages, the rivers have been constantly checked and the downward erosion stayed: in South Africa, the uplift has been so continuous that the rivers have been converted into agents that sawed downwards, and have often found the rate of uplift beyond their powers of erosion, so that waterfalls along their courses have resulted.

This remarkable contrast of the two continental surfaces—the one, the European, very old; the other, the South African, very young—is so striking and so certain, that the relative positions of each of them in the oscillation of land-surfaces, which I have sketched above, cannot be doubted. By establishing the term absolute base-level of erosion, I have endeavoured to give some quantitative expression to a fact which otherwise is difficult to grasp.

There are many problems that will yield to treatment by this touchstone, such as the tilting of continents, the African northwards, the European westwards, the American eastwards; but in South Africa, one has no opportunity of getting together literature on world-wide questions, and I must conclude with the facts as I have observed them locally, and leave to others the task of testing them and applying them to other regions.

Discussion.

The President welcomed the first communication read to this Society by one of that enthusiastic band of geologists, the value of whose work had been recently judged on the spot by the members of the British Association who had visited South Africa. He (the speaker) regarded the checking of the results obtained by study of the geology, by reference to the present conditions of non-change, as a matter of great importance.

Prof. Hull said that he entirely agreed with the Author, that these terraces were the outcome of marine erosion, while the gorges by which they were intersected were due to river-action. The two forms of erosion were here displayed in striking contrast. The occurrence of the marine shells on the 150-to-200-foot shelf was clear evidence, so far as regarded the Bamboes-Bay shelf; but the evidence of marine sculpturing could not be limited by this occurrence, which must be extended to the remarkably-uniform terrace of the 'Uplands,' if not to those above. The submerged Agulhas Bank was of especial interest, and (in the speaker's opinion) was probably the representative of the great 'continental shelf,' or platform, on which the continents of Europe and Africa were planted, and through which the sub-oceanic river-valley had been cut down for several thousand feet. The speaker thought that the paper was well

calculated to throw increased light on those great oscillations of the coast-lands which had taken place from the Pliocene Period down to the present time.

Mr. H. W. Monckton remarked that raised rock-platforms of marine origin, apparently of the same class as those described in the paper, were found along the Norwegian coast, and had been termed strandflade or 'coast-plane' by Dr. Reusch. The speaker thought the term a good one, and better than 'coast-shelf.' He observed that the raised beach of Gower rested upon just such a coast-plane as those found in Norway. He was glad to hear that the Author found in Africa evidence of periods of comparatively-rapid earth-movement, separated by comparatively-long periods of repose, for the speaker had noticed much evidence of similar alternate periods in both Great Britain and Norway.

6. *The* Rocks *of the* Cataracts *of the* River Madeira *and the* Adjoining Portions *of the* Beni *and* Mamoré. By John William Evans, D.Sc., LL.B., F.G.S. (Read November 22nd, 1905.)

[Plate V—Microscope-Sections.]

Contents.

I. General Configuration of the Region.

More than eleven years have passed since the publication of a paper by this Society on 'The Geology of Matto Grosso,'[1] in which I described the rocks that I met with in the area drained by the Upper Paraguay and its tributaries. They include granitoid gneiss, highly-cleaved slates, limestones, sandstones, and shales, and have a prevailing north-easterly and south-westerly strike parallel to the coast-ranges of Southern Brazil. To the northward they are covered unconformably by a younger series of sandstones and shales containing imperfectly-preserved Devonian fossils.[2] These dip gently northward, and form a broad undulating tableland extending from east to west. Still farther north, between latitudes 10° and 4° S. on the Xingú (pronounced Shingu), Dr. Karl von den Steinen[3] found granite, gneiss, and other crystalline rocks. Nothing is said about the strike, but it seems that the trend of the hills was approximately south-west and north-east, as in the basin of the Upper Paraguay.

East of the River Paraguay the high ground changes its trend, and stretches in a north-westerly direction to the cataracts of the Mamoré and Madeira, under the names of the Serra dos Parecis and

[1] Quart. Journ. Geol. Soc. vol. 1 (1894) p. 85.

[2] O. A. Derby, 'Nota sobre a Geologia e Paleontologia de Matto Grosso' Archivos do Museu Nacional do Rio de Janeiro, vol. ix (1890) pp. 59–88. Mr. Derby believes that the two series of sandstones and shales are identical; but although I nowhere saw them in contact, they appeared to be in every way distinct.

[3] 'Durch Central-Brasilien' Leipzig, 1886, pp. 330 (227), 333 (268), and maps III & general.

Cordilheira Geral. At first it constitutes the watershed between the tributaries of the Paraguay and those of the Tapajós, while farther to the north-west it forms the north-eastern boundary of the basin of the River Guaporé or Itenes, which pursues its way in a parallel direction for nearly 400 miles on the north-eastern margin of the alluvial plain of South-Eastern Bolivia, until it unites with the Mamoré. The combined stream turns almost due north across the line of elevation, and, at a height of nearly 500 feet above the sea, its waters commence their descent in a long succession of cataracts to the Amazonian plain.

After passing the falls of Guajará-merim, Guajará-guaçú, Bananeira, Páo Grande, and Lages (in Spanish 'Layes'), the Mamoré arrives at its confluence with the Beni, which has already passed the cataract of Esperanza. The joint stream now takes the name of the Madeira, and flows first northward and then north-eastward across the line of elevation, descending cataract after cataract, until it reaches the settlement of Santo Antonio, at a height of only about 200 feet above the sea. Thence, after a winding course of some 500 miles through swampy forest-clad alluvium, it empties itself into the Amazon.

At the cataracts the rivers make their way through low ridges of crystalline rocks, which form the subject of the present paper. Where these are foliated their strike is, as a rule, north-west and south-east, in the same direction as the ridges. The total width of this hilly region is about 170 miles, although the rivers in their windings cover a much longer distance in traversing it.

The hills continue to the north-westward beyond the cataracts, but how far they extend is not known. We are told of falls on the River Ituxy, a tributary of the Purus, which flows on the north west of, and more or less parallel to, the Madeira, so that the line of crystalline rocks probably reaches at least thus far. There is also a rapid, known as the 'Cachoeira,' on the Purus, still farther in the same direction, which may perhaps be referred to the same cause. It is noteworthy, too, that the Purus, the Tarahuacá-Juruá,[1] the Yacarana or Yavary, and the Ucayali-Marañon, all have a change of direction corresponding to that of the Mamoré-Madeira at the cataracts, and that the points at which these changes of direction occur are in continuation of the line of strike of the crystalline rocks of the cataracts of the Madeira.

This may be explained by the fact that the general inclination of the country on the borders of Brazil, Bolivia, and Peru is slightly to the east of north, while the elevation that forms the cataracts runs obliquely across it: the result being that, when the rivers reach the ridge, they are diverted down the slope north-westward until a point of weakness or inferior elevation is reached, by which a passage is effected.

It is true that there is no record of hard rocks having been observed on most of the rivers that I have mentioned, but they

[1] That is, the stream formed by those rivers successively.

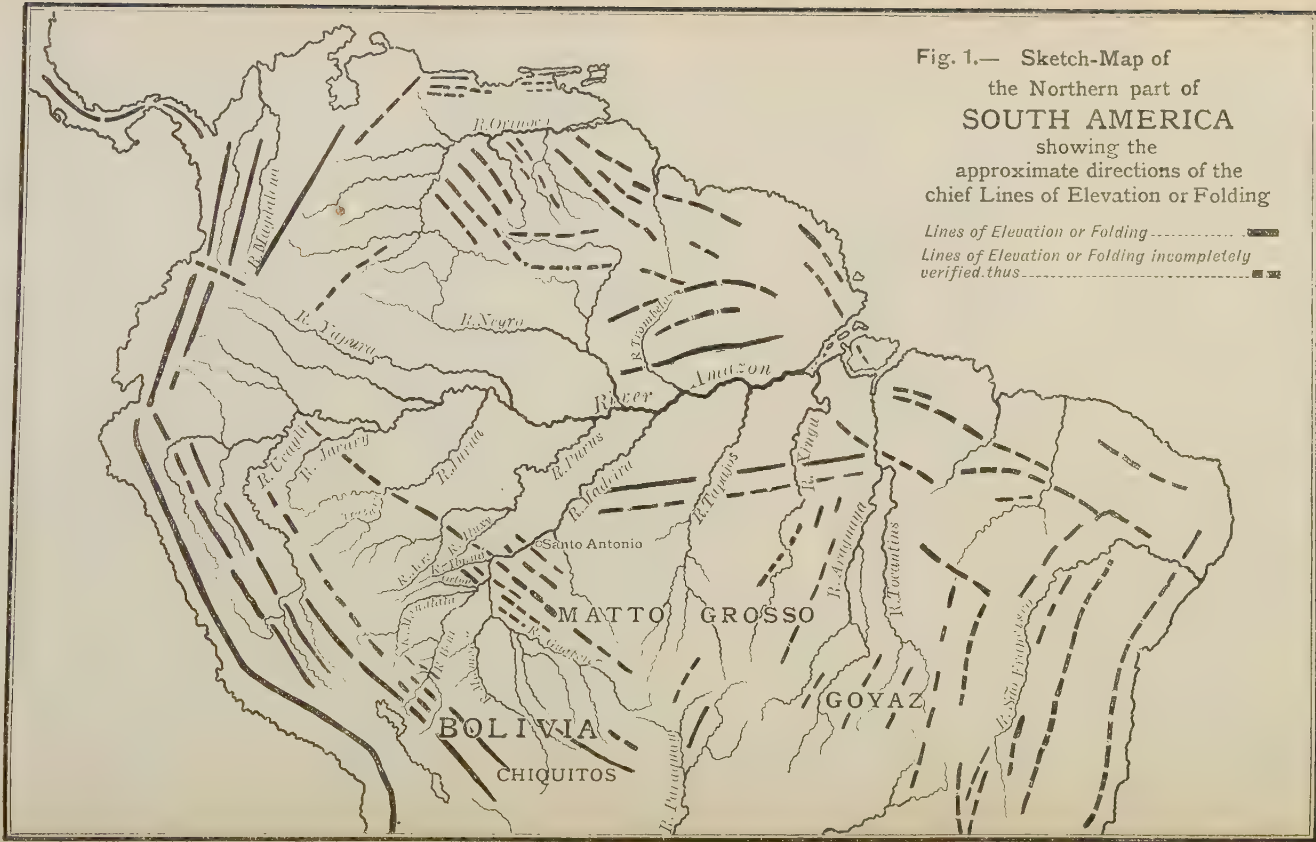


Fig. 1.— Sketch-Map of the Northern part of SOUTH AMERICA showing the approximate directions of the chief Lines of Elevation or Folding

[For 'Ucayli' *read* 'Ucayali'; for 'Javary' *read* 'Yavary'; and for 'Trahuaca' *read* 'Tarahuacá.']

are still imperfectly known; and in the tropics the process of lateritization often renders slates and crystalline rocks rich in alumina almost indistinguishable from recently-formed alluvium. It must be remembered, too, that there is a wide belt east of the Andes which appears to have been depressed, and where the whole country is flooded in the rainy season. In this region there must be a considerable accumulation of alluvium, which may now cover the ancient rocks of the ridge.

We have, therefore, evidence of an important axis of folding and elevation, with a south-easterly and north-westerly direction,[1] in the centre of South America; and there is reason to believe that it extends for a distance of 1200 miles, from $14\frac{1}{2}°$ lat. S. and 59° long. W. to 4° lat. S. and 73 long. W. near Iquitos. Its direction is parallel to that of the Andes in Northern Bolivia and Southern Peru, as well as to a small intermediate axis of elevation in Chiquitos in South-Eastern Bolivia.[2]

These lines of folding follow the north-westerly and south-easterly strike, which is so common on the earth's surface for some distance on either side of the Equator. It also appears to prevail in Southern Venezuela, in Guiana, and in North-Eastern Brazil, where a barrier is believed by Dr. Friedrich Katzer[3] to have formerly stretched across the site of the mouth of the Amazon.

There appear to be four principal directions of folding or elevation in South America, namely:

(1) The north-westerly and south-easterly strike already described, which is also met with in the south of the continent in Argentina and Patagonia, as well as in Tierra del Fuego and the Falkland Islands.

(2) A direction roughly at right-angles to the former, approximately north-east and south-west, following the coast of Brazil south of Cape San Roque. It also occurs on the Upper Paraguay and the Xingú, and in the Colombian Andes.

(3) An east-and-west strike seen in Northern Venezuela and Trinidad, and in the Amazonian basin, which consists broadly of a syncline bounded by two lines of elevation on the north and south.

(4) The north-and-south line of the Andes, from Southern Bolivia to Patagonia.

These directions are roughly indicated in the sketch-map which forms fig. 1 (p. 90). In the present imperfect state of our knowledge of the geology of South America, it is impossible to give their exact positions.

The movements along all these lines appear to have extended over a considerable period. The north-easterly and south-westerly folding of Matto Grosso was mainly pre-Devonian, while the north-westerly and south-easterly movements in the Andes extended to at least post-Carboniferous times. The north-and-south

[1] More exactly north 55° west.

[2] A. d'Orbigny, 'Voyage dans l'Amérique Méridionale, exécuté pendant les années 1826-33' vol. iii, pt. 3 (Géologie), Paris 1842, pp. 183-99; and J. W. Evans, 'The Geology of Matto Grosso' Quart. Journ. Geol. Soc. vol. l (1894) p. 96.

[3] 'Grundzüge der Geologie des Unteren Amazonasgebietes' Leipzig, 1903 p. 240.

and east-and-west lines of movement appear to be of Tertiary and Quaternary age. Along the Pacific coast, movements with lines of strike parallel to the shore-line have, it need scarcely be said, continued down to historical times.

II. Previous Work.

With the exception of some brief notes by Joseph and Franz Keller and Col. Church,[1] the only description which has yet been published of the rocks of the cataracts is that given by Dr. João Severiano da Fonseca, who in the year 1877 descended the rivers Guaporé, Mamoré, and Madeira with the Commission for the delimitation of the frontier between Brazil and Bolivia.[2] As this book is comparatively inaccessible to geologists in this country, I have translated, and reproduce here, those portions which seemed to be of interest in connection with this paper.

The following paragraphs refer to the geology of the cataracts as a whole:—

Vol. ii, p. 280. 'The rocks of these cataracts are of plutonic formation, and reveal at the first glance their volcanic origin, modified perhaps by metamorphism. Some were difficult for me to classify, on account of the obscurity of their characters; in others the mineralogical facies was satisfactorily determinable. The great trachytic pavements, which are nearly smooth, and either of a ferruginous hue or shining black like pitch, are formed in many places of superposed beds, which are more or less undulating and have curvilinear borders, as if they had been derived from viscid melted material poured forth in great outbursts, and forming sheets of which the later solidified before they reached the distance to which the earlier had extended. Here and there appeared large rock-masses, some prismatic in shape, others rounded: in one place were dykes of diorite and of elvan; in another loose blocks. Some were split in the middle by a mere crack, others by a gap of more than a fathom in width.'

'There were likewise large cauldrons, holes in the pavement, perfectly rounded, the formation of which is easily explained by the attrition of stones rolled about in small depressions which, little by little, with the movement of the waters and the passage of centuries, become larger and more rounded. But it is not so easy to explain the elliptical holes in some of these pavements .... all are of the same dimensions, and as if arranged in uniform directions one after the other in two or three lines, so that they call to memory, though without any resemblance, human footsteps. The most notable are those of the cataracts of the Madeira, Bananeira, Ribeirão, and Paredão. Their dimensions are: 1 to 3 decimetres long, a third more or less of this broad, and nearly as much deep, always preserving an ellipsoidal form. Are they spaces formerly occupied by bodies easily disintegrated or decomposed by the waters, and that in time became vacuous? As for the pavements, in spite of their being varnished by the attrition of the water and brilliant with a black metallic polish, it is not difficult to classify them by their texture and system of agglutination. They are hornblende-porphyries, obsidians, syenites, petrosilex, etc.—all felspathic rocks. The canga (ferruginous conglomerate) appears in lofty crags of a reddish-black colour, whence they have received the Tupic name tupanhona canga. At the same time, dykes of

[1] Franz Keller-Leuzinger, 'Vom Amazonas & Madeira' Stuttgart, 1874; and George Earl Church, 'The Route to Bolivia *via* the River Amazon (a Report to the Governments of Bolivia & Brazil)' London, 1877, p. 186.

[2] 'Viagem ao Redor do Brasil' Rio de Janeiro, 1880–81.

compact eurite rise to form other crags: either by breaking through the metamorphic crust, or because they are enveloped by decomposed gneiss the surface of which, now eroded by lapse of time, was formerly at the same level as that of the dykes.'

'In the large cauldrons, which are dry, there are not infrequently conglomerates of small fragments of dioritic rocks, principally black diorite, which appeared to me to be cemented with hydrate of iron.'

'I brought back with me some specimens of the most notable of these rocks, as well as of the pebbles inserted in the cracks of the pavements, where a secondary process of agglutination with the sand of the river and the clay which it carries in suspension, forms a puddingstone...... These sedimentary rocks are rare in the localities where the stream runs strongly, but very frequent in the backwaters.'

In one of the cataracts, he believes that of Bananeira, he found a piece of petrified charcoal formed of bright shining lamellæ, which is now in the Museum of the Archæological Institute of Alagoa.

It will be seen from the following pages that, although I have been able to confirm some of Dr. Fonseca's statements, I never saw any rocks that could be classed as trachytes, or that showed any evidence of having flowed at the surface.

III. Geological and Petrological Observations.

(1) Between the Andes and the Cataracts.

In the year 1902, when returning from Bolivia by way of the Beni and Madeira, I had an opportunity of examining the rock-exposures on those rivers.

Leaving the Bala-Susi Mountains, the last outworks of the Andes, behind me at Rurenabaque, I descended the Beni until I reached, twenty days later, the 'rubber-metropolis' Riveralta, at the mouth of the Manutata (Madre de Dios). Throughout this distance (some 220 miles in a direct line, and 470 following the stream) the Beni flows in innumerable meanders through a wide forest-plain, between 500 and 600 feet above the sea. For the greater portion of the distance the ground is scarcely raised above the water, although the margin of the river is usually marked by a low bank or levée forming a natural breakwater, which, however, is often flooded when the river is high. Beyond are lagoons representing abandoned reaches of the river. At a greater distance from the Andes there are, however, tracts of rising ground, occasionally as much as 50 or 60 feet above the level of the stream, which sometimes cuts into them, forming well-marked cliffs. These elevations are built up of argillaceous or fine sandy materials with varying amounts of iron, which is sometimes present in such quantity as to constitute a hard stone. With this exception there is no solid rock, either *in situ* or in fragments larger than fine sand-grains,[1] below the rapid of Altamarani, some 10 miles below Rurenabaque, where the river, slackening its pace after leaving the mountains, has thrown down a thick bank of more or less rounded fragments.

[1] Even this sand is remarkably poor in heavy minerals.

[For 'Arayá' *read* 'Aroyá.']

After a short stay at Riveralta, literally 'high bank,' which stands on a cliff such as I have described, I ascended the Manutata, and thence travelled overland to the Orton. Between the two rivers is a narrow plateau, extending for many miles in the direction of its length, and raised some 40 feet above the level of the lower forest. Though it is possible that these tracts of comparatively-high ground may in some places be formed of hard rocks decomposed by lateritization, there can be little doubt that, in the great majority of cases, the materials of which they are composed are of fluviatile origin, and were laid down by rivers under conditions similar to those which now exist. They are, therefore, in all probability the remains of the former surface of an ancient alluvium, the rest of which was removed by the present rivers, whose level has been lowered by the wearing-away of the barrier at the cataracts. I was unable to see any definite evidence of local changes of relative level in these deposits, which may be provisionally referred to the 'Neogene' of Dr. Friedrich Katzer.[1]

I followed the Orton to its confluence with the Beni, and subsequently descended the latter river.

(2) The Cataract of Esperanza on the Beni.

A short distance below the mouth of the Orton the Beni passes at the 'Correnteza,' or rapid, a line of rocks, said to be thirteen in number, projecting here and there above the water, and having a general north-westerly and south-easterly direction. Although there is no perceptible fall at this point, the current runs with considerable force,[2] and it was impossible to stop the boat to examine the rocks. This rapid forms the *cabecera* or head of the cataract of Esperanza.[3]

A mile or two farther down stream the cataract itself is reached, where the river passes a number of ridges of crystalline rocks which form low elevations in the forest on either side. The principal fall has a height of 9 or 10 feet, and below it are rapids which constitute the *coda* or tail of the cataract, where the river passes yet another ridge of rock.

Megascopically the rock (M 1)[4] of the Esperanza Cataract shows a granular mixture of pinkish felspar, with a little greyish quartz and specks of a black mica, the latter, however, being mostly aggregated into parallel lenticles or irregular masses. The specific gravity is 2·633. The strike of the foliation is fairly constant, in a west-north-westerly and east-south-easterly direction.

[1] 'Grundzüge der Geologie des Unteren Amazonasgebietes' 1903, p. 108.

[2] In 1897 an island at this point was swept away by a flood.

[3] So called from the words of the devoted Indian who accompanied Dr. Heath, the first European to descend the Beni from the Andes to its mouth: 'Then let us call this cataract *Esperanza*, for now that we have passed it we have hope of life.'

[4] Numbers in parentheses preceded by the letter M refer to the rock-specimens and microscope-sections now in the Mineralogical Department of the British Museum (Natural History).

Under the microscope, the felspar is seen to consist partly of microcline and orthoclase, both with microperthitic inclusions on a minute scale, and partly of albite, which sometimes contains more or less rectangular inclusions of microcline or orthoclase arranged along definite lines and extinguishing together. Quartz occurs in small oval or circular blebs, such as are characteristic of granulites, or in rounded lozenge-shaped individuals which appear to be sections of the double pyramid, for the extinctions are parallel to the diagonals. Other crystals are more or less hexagonal, and occasionally these are dark in all positions of the nicols. These grains or crystals of quartz are usually found as inclusions in felspars, or penetrating into their margins; while, in some instances, the felspar appears to fill the irregular intervals between crystals of quartz, or the eroded cavities in that mineral. There can be no doubt that the crystallization of the quartz must, in all these cases, have preceded that of most of the felspar. Micrographic structure, however, occasionally occurs where the two must have crystallized together; and there are also cases where the quartz fills the interstices between felspars, and must have been the last mineral to separate out.

There is a fair amount of biotite and brown hornblende, which is sometimes intergrown with quartz in a kind of micrographic structure. I also observed a large, rounded, greenish-yellow, highly-refracting isotropic crystal, 1·25 mm. in diameter, surrounded by hornblendes, which is altered externally to a yellow decomposition-product with low birefringence. The mineral is traversed by cracks filled partly with a mineral of high birefringence, about double that of quartz, and partly with fluor. It may, perhaps, be a silicate of the rare earths allied to pyrochlore.

A few grains of apatite, zircon, and magnetite are present. The rock is rather fine-grained, the largest crystals, felspar and quartz, not exceeding 3 millimetres in diameter.

The foliation was not apparent under the microscope.

In some bands or veins (M 1 *b*) the constituents approach a centimetre in diameter, and the dark constituents almost completely fail; so that the rock may be described as a rather coarse-grained haplite, consisting of quartz, a little microcline, and albite. In the last are numerous minute plates, usually appearing like needles in thin section. These are probably hydrous soda-mica, the result of incipient decomposition.

Elsewhere (M 1 *a*) there are dark bands in the gneiss that reveal, under the microscope, an entirely-different composition. The felspar is plagioclase, showing albite and frequently also pericline-twinning in alternately broad and narrow bands. The maximum angle of extinction with the lamellæ of the albite-twinning, in sections perpendicular to the brachypinakoid, is 20°, and the refractive index is well above that of the slow (extraordinary) vibrations in quartz. The felspar is, therefore, apparently an acid labradorite. It contains numerous minute inclusions of hornblende, quartz, and apatite, and occasionally lines of rectangular isotropic inclusions

which are probably filled with liquid. Quartz occurs in small blebs, and shows rounded idiomorphic boundaries. There is abundance of brown prismatic hornblende, with a maximum extinction-angle between the direction of vibration of the slower wave-surface and the trace of the cleavage of about 24°, and strong pleochroism. It contains inclusions of quartz.[1] Crystals of pyroxene are also present; and much of it is distinctly pleochroic, ranging between very pale shades of green and yellowish-brown. This pyroxene appears to be partly augite and partly enstatite. Some of the augite shows signs of alteration into diallage. Irregular masses of magnetite also occur. The rock, which has a specific gravity of 3·012, is apparently on the border-line between a micro-diorite and a fine-grained dolerite.

In the neighbourhood of the cataract, pebbles again appear in the river-beaches. Some are formed of crystalline rocks; but the majority are derived from sedimentary beds, and include consolidated grits or quartzites and silicified limestone or chert, showing traces of stratification. The latter contain organic remains with concretions and rhombohedra of a ferruginous carbonate, perhaps ankerite, which has been oxidized to a yellow-brown tint; and a groundmass of colloid and chalcedonic silica.

I submitted the microscope-sections, that I had had made, to Dr. George J. Hinde, F.R.S. He kindly examined them, and wrote to me as follows:—

'The circular and elliptical sections in slide (M 1 *e*) are sponge-spicules. Probably they are the anchoring spicules of siliceous Hexactinellids. The inner tube is the axial canal of the spicule. They seem to be fairly common in this chert. There are traces of rods in slide (M 1 *c*); these are probably also spicules, but the chert is so much altered in this slide, that one cannot be positive.

'There are other bodies in slide (M 1 *e*) the nature of which is unknown to me. One is a thin shell, almond-shaped in section, which may be the carapace of some crustacean; a smaller form may be of similar origin.

'There is also an imperfect flask-shaped body with a reticulate structure, of which I cannot guess the character.

'I do not see anything that can be considered radiolarian; but the chert has been very much altered and, judging from the changes which have affected the sponge-spicules, the radiolaria, if originally present, would have been obliterated beyond recognition.'

In a subsequent letter Dr. Hinde states that he considers the chert to be marine, and that it may well be Palæozoic, although the evidence is insufficient to prove it. Rocks containing Hexactinellid sponge-spicules occur to the north of the Amazon on the rivers Trombetas and Maecurú. The accompanying fossils indicate a horizon at the base of the Silurian (using that expression so as to exclude the Ordovician).[2]

The sedimentary rocks cannot have come from the Andes, the

[1] See p. 121, footnote 1.

[2] F. Katzer, 'Grundzüge der Geologie des Unteren Amazonasgebietes' 1903, pp. 218, 222.

river being far too sluggish to carry stones of such size. They must be derived from strata flanking the crystalline rocks on the south-west, possibly from the reef of thirteen rocks above Esperanza.

The occurrence of marine beds in this region of alluvium and crystalline rocks is of great interest. I may mention that I found pebbles of silicified oolite in the Upper Paraguay, at Santa Cruz, Barra dos Bugres.[1]

(3) The Cataracts of the Mamoré.

Leaving the Esperanza Cataract behind me, I descended the river to Villa Bella, which is situated on the tongue of land between the Beni and the Mamoré. Thence I made a short journey up the latter river, in a canoe, to the rapids of Lages, where broad rock-pavements, which give their name to the cataract, are exposed when the river is low.

Megascopically this rock (M 2 & 3) appears to consist of quartz and felspar speckled with flakes of black mica. The size of the constituents varies from place to place, but the grain is always rather fine. There is distinct banding, which has more the appearance of flow-structure than of the foliation of gneiss. The rock splits somewhat easily, but in a direction which is parallel rather with the surface than with the planes of banding. Its specific gravity is 2·66.

A microscope-section of the coarser (M 2) material (Pl. V, figs. 1 & 2) shows abundance of felspar, including microcline—sometimes with microperthitic inclusions, and plagioclase with lamellar twinning. The latter appears to be intermediate between albite and oligoclase; it shows in some cases inclusions the boundaries of which are parallel with those of the host; they have lower refraction and birefringence, and are probably orthoclase. Quartz occurs, both independently and as inclusions in the felspar; as in the rock of the Esperanza Cataract, it appears to have crystallized out before the latter mineral. The sections often show crystallized outlines, but are sometimes only rounded blebs. Similar rounded inclusions of felspar, especially microcline, also occur. In some cases, the felspar appears to have crystallized in the cavities of the quartz. Micrographic intergrowth is fairly common. There is much brown and green mica representing biotite in different stages of alteration into chlorite. Epidote, apatite, and magnetite are also present.

The finer-grained specimens (M 3) are similar, but show crystals of yellowish-green hornblende, with an extinction-angle (between the direction of slower vibration and the cleavage) which reaches a maximum of 29°. The colours of different directions of vibration vary between yellowish-green and dark green. The largest quartz- and felspar-crystals measure about a millimetre in diameter, but numerous small quartz- and felspar (microcline)-grains occur, both

[1] 'The Geology of Matto Grosso' Quart. Journ. Geol. Soc. vol. l (1894) p. 91.

independently, and as inclusions, which in size and shape recall the minerals of a granulite.

I did not ascend the Mamoré any farther. A. d'Orbigny,[1] who spent a few days at Beira on the right bank of the Guaporé or Itenes, some distance above its junction with the Mamoré, found, on the south-western flank of the Serra dos Parecis or Cordilheira Geral, hills formed of friable sandstones which were very ferruginous, and generally red in colour. They were of great thickness, and dipped south-eastward[2] at an angle of 12° or 15°. These sandstones, which appeared to extend far to the north, were covered in the neighbourhood of the river by ferruginous conglomerates containing much oxide of iron, and forming perfectly-horizontal beds.

Dr. Fonseca states[3] that, at the cataract of Guajará-merim, a chain of rocks some 150 metres broad traverses the river from side to side, expanding on its margins into two enormous pavements of dioritic appearance. In some places there is, he says, a porous formation of a kind of varnished canga (ferruginous quartz-conglomerate) 'resembling phonolite;' while on the bank, amid the vegetation, 'argillotalcose schists' without visible stratification are exposed. He also states that, above the cataract of Lages, at the mouth of the river of the same name, the rocks are covered by sands resting upon dark-grey clay with 'nuclei of silex' (*op. cit.* p. 270).

According to Col. Church ('The Route to Bolivia *via* the River Amazon' 1877, p. 187) the upper rapids are composed of ferruginous conglomerate, the surface of which is as black as ink, and he quotes the following from a report by the Kellers:—

'The ferruginous conglomerate which is found on the surface of the earth, only covered with a bed of clay of from 5 to 6 metres of thickness, is a conglomerate of gritstone, little pieces of dolerite cemented with oxide of iron, full of openings and cavities which give it the appearance of a sponge or scoria. Its beds are generally horizontal, and are from 4 to 5 metres thick. In the inferior beds the seams are smaller, at some points disappearing entirely, and forming then a more homogeneous mass of red gritstone, very argillaceous.'

They declare that this formation extends over more than 12 degrees of latitude. Col. Church (*loc. cit.*) further states that the rock of the Bananeira rapid is

'distinctly granitic, but with much iron disseminated. The surface of the rocks, wherever the water has been flowing over them, is blacker than ink . . . . the hornblende, feldspar, and quartz are well disseminated in the rock.'

(4) The Cataracts of the Madeira.

Immediately below the confluence of the Beni and Mamoré is the cataract of Madeira, where the river of the same name flows rapidly for 2 miles between rocky islands, the total fall being over 8 feet ($2\frac{1}{2}$ metres).

[1] 'Voyage dans l'Amérique méridionale, exécuté pendant les années 1826–33,' vol. iii, pt. 3 (Géologie) Paris, 1842, p. 203.

[2] This is not the dip that would have been expected. Possibly it may be a verbal mistake for south-westward.

[3] 'Viagem ao Redor do Brasil' vol. ii (1881) p. 263.

The rock is a pale granitoid or haplite-gneiss, in which the ferromagnesian minerals are but little developed.[1] In some places it is fairly coarse-grained, and in pegmatoid veins the constituents measure as much as 2 centimetres in diameter.

On examination of a microscope-section (M 4 *a*) from one of these coarser portions, it appears to be mainly composed of irregular masses of quartz, microcline, and orthoclase. Sometimes the border of the quartz sends out a number of rounded prominences in crystalline continuity, which penetrate the felspar micrographically. The felspar is altered in places into a colourless mineral with a higher refractive index, and a negative sign of the principal zone. The relative retardation of the two directions of vibration is higher than in quartz, the birefringence reaching a maximum of about 0·029, or 29 thousandths.[2] This is probably a somewhat hydrous muscovite; the cleavage is, however, not well marked. Plagioclase intermediate between albite and oligoclase is also present.

Elsewhere the rock (M 4) shows megascopically a fine granular mixture of quartz and felspar, with small aggregates and rods of a dark-green mineral. Under the microscope it is seen to be a granulitic rock, consisting of a mixture of rounded quartz-grains measuring up to half a millimetre in diameter, and plagioclase (albite-oligoclase) of about the same size. The general appearance has a curious resemblance to some quartzites where the grains are uniform in size. There are a certain number of felspars that show only Carlsbad-twinning or none at all; but the refractive index appears to be identical with those showing twin-lamellation, and they have

[1] Dr. Fonseca describes here the occurrence in the 'syenite'-rocks of the oval and elliptical holes already mentioned.

[2] The birefringence or difference between the indices of refraction of the two directions of vibration represents the relative retardation in a unit of length, and might be termed the rate of relative retardation. If k be the total relative retardation between the two directions of vibration, l the thickness of the section, and d the birefringence or rate of relative retardation, then $d=\frac{k}{l}$. In this particular case the observed relative retardation (k) was 670 micromillimetres (millionths of a millimetre), and the thickness was 23,000 micromillimetres, so that d was equal to $670 \div 23{,}000 = {\cdot}029$. It is, however, convenient to measure the thickness of the section in microns (a thousandth of a millimetre = 1000 micromillimetres), and to take as a practical unit of birefringence the number of micromillimetres of relative retardation in a micron: thus avoiding the use of small decimal fractions. If then D be the rate of relative retardation in micromillimetres per micron, k the relative retardation in micromillimetres, and L the thickness in microns, $D = \frac{k}{L} = \frac{670}{23} = 29$.

The unit rate of relative retardation in micromillimetres per micron is $\frac{1}{1000}$ of the absolute unit of birefringence or rate of relative retardation, in which both the relative retardation and the distance are expressed in the same units; it is, therefore, conveniently spoken of as a 'thousandth.' Perhaps a 'millesim' would be better; see a paper in the Mineralogical Magazine, vol. xiv (1905) p. 87. The words micron and micromillimetre are here used in accordance with the rules laid down by the British Association for the Advancement of Science.

probably the same composition. This view is supported by the fact that there are many felspars in which the repeated twinning is only just perceptible. Many of the plagioclases contain approximately-rectangular inclusions, arranged parallel with crystallographic directions of the host. These have a low refractive index, and are apparently isotropic; they probably represent spaces formed by the action of solvents, and filled with liquid. No microcline is visible. The small quartz-grains are enclosed in the felspar, and are often idiomorphic. There are also a number of minute, more or less rounded inclusions that are arranged in lines passing through all the constituents of the rock. Flakes of biotite more or less converted into chlorite are present in considerable numbers.

Veins of quartz are observed in the rocks of this cataract; and pebbles of the same material are bound together by ferruginous cement, to form a hard conglomerate that is met with here and there in the alluvium.

The rocks are, as a rule, distinctly foliated on a large scale. The strike is very variable. The band of crystalline rocks rises to low elevations on either side of the river; and it is said that a day's journey into the forest to the south-east there are considerable hills.

The river now runs for 10 miles through low alluvial land, until at the cataract or rapid of Misericordia, another band of crystalline rocks is passed. I landed on the left bank, a short distance above the cataract, and found the gneiss stretching into the forest in low rounded knolls, which may have been worn by the river when it flowed at a rather higher level.

To the naked eye, the rock (M 5) appears to be a gneiss, consisting of an aggregate of small grains of pink felspar, occasional quartz, and bands of a dark-green material. It has a specific gravity of 2·63. The strike of the foliation is north-north-westerly and south-south-easterly, but it is apparently somewhat variable.

Under the microscope, abundant microcline is seen, up to a diameter of 2 or 3 millimetres; there is also some microperthite, as well as albite-oligoclase containing minute inclusions of a colourless material, similar to that seen in the microcline of the haplite from the Madeira Cataract: in this case they probably represent a hydrous soda-mica. There are large crystals of quartz, of about the same size as the felspars, and separated from them by a ragged irregular boundary that corresponds to the crystalline outlines of neither; while smaller blebs or rounded crystals of quartz, such as have been already described, occur as inclusions in the felspars. In the greater portion of the rock, the ferromagnesian minerals are present only in small amount, being represented by flakes of mica and hornblendes which elsewhere form the coloured bands. A few crystals of sphene are also visible.

After passing Misericordia, a line of hills is seen in the distance, which are passed in the cataract of Ribeirão, so called from a

small river[1] that enters the Madeira midway down the cataract. As is usually the case, the main hills are on the left bank.

This is one of the largest and most formidable of the cataracts. For the distance of several miles, the river rushes through rocky channels amidst numerous islets. The rocks consist of gneisses similar in character to those at Misericordia.[2]

I have only one specimen (M 5 *a*) from this cataract. In a hand-specimen, it would be described as a haplite of medium grain, being composed of grey quartz and white felspar, without any noticeable amount of ferruginous minerals.

Under the microscope, it shows abundant quartz in irregular grains, measuring up to a couple of millimetres in diameter. The smaller quartzes are either idiomorphic, or form rounded blebs, and are often included in the felspars. Microcline is very common, and there is occasionally a little oligoclase. A green hornblende with low extinction-angle, biotite, apatite, and sphene are also found.

In the dry potholes and other hollows, a ferruginous conglomerate is observed, containing vein-quartz and decomposed felspathic material. There are also hollows in it left by the rotting-out of small twigs and fragments of wood.

We passed the cataracts of Periquitos and Aráras[3] without landing. Thence there is a stretch of 50 miles without cataracts, where the Madeira runs through alluvial forest, the soil of which is, as a general rule, raised but little above the river. A short distance below Aráras, we landed on a large bank of mud and sand. This had dried after the fall of the river, which was nearly at its lowest, and had split into cracks, which were subsequently filled with blown sand. It would be interesting to know whether the phenomenon has been observed in older strata. Cases of similar cracks being filled with aqueous deposits have been frequently reported.[4]

About 30 miles below Aráras one reaches the mouth of the Abuná, flowing in from the west-south-west; and the Madeira, which has hitherto held an almost northerly course, now turns to the east-north-east, as if in continuation of the Abuná, and crosses the crystalline ridges nearly at right-angles, instead of obliquely as before. It is this bend which is repeated by the other tributaries

[1] The sand of this stream is said to be auriferous.

[2] In 'Viagem ao Redor do Brasil' vol. ii (1881) p. 283, Fonseca describes the upper portion as formed of great pavements covered with blocks of diorite, some loose, others forming dykes; there were also cauldrons and elliptical holes such as have been already described.

[3] F. Keller-Leuzinger ('Vom Amazonas & Madeira' 1874, p. 44) states that the rock at this cataract is a 'lustrous black-green gneiss.'

[4] According to Col. Church ('The Route to Bolivia *via* the River Amazon' 1877, p. 187), 'about 7 miles down stream from Araras, and abutting on the river, are two singular bluffs, perhaps 100 feet high each, and perpendicular. They appear like isolated hills which have been sawn across by the river, and are of the stiff red-clay formation common to the whole of Brazil, and especially to the Amazon Valley.' I did not notice these, but we travelled a considerable distance above the Abuná before daybreak. Undoubtedly the banks were unusually high at this part of the river.

of the Amazon farther to the north-west, in the manner that I have described.

At the next cataract, that of Pederneira, the rock (M 6) is a strongly-foliated gneiss, consisting of pink felspar with a dark-green constituent. Where the latter is predominant, the felspar occurs in small porphyritic eyes. The strike is usually about north 60° west, but in places it is due east and west. At one point there is a narrow vein of chalcedonic quartz, from which flints for use as knives and for striking fire were formerly obtained. The name of the cataract refers to these flints.

Just below the cataract, the Madeira receives on the left the Rio Arapongas or Ferreiros, which appears to flow in a longitudinal valley. The river then turns to the east. I was told that on the Arapongas were slaty rocks with quartz-reefs. Col. Church ('The Route to Bolivia *via* the River Amazon' 1877, p. 188) also states that he recognized slates on the main stream. He has kindly furnished me with the following extract from his journal:—

'On the western extremity of the great bend I find a 30-foot bluff of slate. It is probably this slate-formation which catches the river after it shoots so far to the westward, and turns it at a right angle to the north-north-east.'

I did not see these slates; but the river is wide, and the course of my canoe was near the left bank.

A microscopical examination of the rock of the cataract shows a highly-foliated structure. There is much plagioclase that has a crushed appearance; it is usually untwinned. Microcline occurs in large comparatively-unaltered crystals, which sometimes contain microperthitic inclusions. Orthoclase is also present. One large crystal, apparently a Carlsbad-twin of microcline, but with the characteristic twin-striations very faintly developed, includes numerous crystals of andalusite, which have dark centres comparable to those of chiastolite; thin plates of a hydrous mica, and rod-like forms which may perhaps be referred to sillimannite, also occur. There is abundant quartz, especially along certain planes, with irregular interlocked boundaries. Hornblende and biotite occur in lenticles, as well as occasional crystals of sphene with irregular boundaries. The formation of the andalusite in this rock is, no doubt, due to metamorphism similar to that which causes the development of chiastolite in a slate.

From Pederneira we could see to the south-east the hills on the left of the river, near the cataract of Paredão, so called from the wall-like outcrop traversed at that point.[1]

The rock is a fairly-coarse gneiss, the felspars in some places

[1] Dr. Fonseca describes ('Viagem ao Redor do Brasil' vol. ii, 1881, p. 289) the mass or platform on the right bank as having a width of 126 metres. 'This mass,' he says, 'is a most magnificent specimen of rock, with its beds one above the other revealing the state of liquefaction in which they were deposited, like a great outpouring of honey thick and ready to crystallize, which moves slowly, sliding on in broad sheets above beds already solidified. This shows that either the crystallization was very rapid, or the streams of the material in fusion were very sluggish in their flow. But, closer to the river, the rock

measuring as much as a centimetre across, and no doubt larger specimens occur. It shows in hand-specimens (M 6 *a*; specific gravity = 2·61) a considerable amount of quartz occasionally idiomorphic, pink felspar, and mica. Under the microscope porphyritic crystals of microcline-perthite are visible, which sometimes reach a diameter of 4 millimetres. There are also large crystals of quartz and albite, the latter filled with numerous minute enclosures, which show much greater relative retardation than the felspar, and are probably paragonite. The groundmass is an aggregate of more or less rounded crystals of quartz, microcline, and a little basic oligoclase measuring up to half a millimetre in diameter.

Another specimen (M 6 *b*), from the same locality, appears megascopically to be similar, but with a finer grain. Under the microscope it shows abundant quartz, amounting to about half the bulk of the rock, and occurring in numerous small crystals up to about 3 millimetres, which, more often than not, show indications of crystalline outline. They are frequently included in the felspar, which is partly microcline and partly albite. There are also a few flakes of decomposed biotite.

Those portions of the rock that were frequently covered by the river were, like many rocks in similar situations in other tropical rivers, coated with a black film consisting mainly of manganese-oxide and ferric oxide.[1] Both the bare gneiss and the blackened portion had a brilliant polish, the result, I imagine, of the action of the wind-borne sand from the beaches and banks which are left dry when the river falls. It must be remembered, however, that the river-water is heavily charged with sand, and the polishing may

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loses this character: instead of being smooth and polished, it acquires a highly-irregular surface. Above it rise dykes of diorite, crags from 3 to 6 metres in height; while close at hand sink abysses, or the rock exhibits broad and deep erosions, which become navigable channels of the river when the water is sufficiently high. The platform terminates at the river in one of these cliffs, 4 metres in height, which throughout its extent forms the margin of the river. In the portion left dry by the river, one sees circular cauldrons a metre and more in diameter and depth, and small elliptical excavations of the same size as those observed in the other cataracts. Some of the rock-platforms are of a shining red colour, perhaps due to ferric oxide; others are of a brilliant black, due to the oxide of the same metal or peroxide of manganese. Here and there again are blocks split longitudinally, which preserve a remarkable parallelism between the faces of the crack, the salient portions of one side corresponding to the re-entrant portions of the other. Some 50 metres below the cataract, and on the same bank, is another wall (*paredão*) like that of Aráras, formed of superposed rocks of sandstone and gneiss affecting the form of trap-rocks with such closeness that it resembles an old wall in ruins. The texture of the gneiss resembles that of basalt, but the fracture is more conchoidal. It was this mass that gave the cataract its name. Thence on to the cataract of the Trez Irmãos, which is 44 kilometres distant, the river continues studded with rocks, principally on the left-hand side.'

I saw no evidence of the occurrence of volcanic rocks at Paredão, or anything in the nature of an abyss. Col. Church ('The Route to Bolivia *via* the River Amazon' 1877, p. 188) says that 'the granitic formation which bars the river is very coarse and highly feldspathic. Large crystals of feldspar, several inches in length, are disseminated through the rock, and where the floods have worn them they are as smooth as glass.'

[1] See *post*, p. 121.

have taken place to some extent under water, although it is very doubtful whether such is the case.

From the cataract of Paredão to that of Trez Irmãos (the Three Brothers), crystalline rocks occasionally appear in the river-bed, and hills are usually visible, mainly on the left (north) of the river, which has no doubt been gradually shifting its course to the convex side of the bend, while a tract of alluvial ground has been left on the concave margin.

The cataract of the Trez Irmãos owes its name to three hills on the left of the river, in continuation of the ridge which is traversed by the Madeira at this point.[1] We passed without landing, and continued our way down the river in a roughly north-east direction to the cataract known as Salto do Girão (Leap of the Whirlpool). Here the river, which had expanded shortly before to a width of $2\frac{1}{2}$ miles, is contracted by hills, and passes over a fall 25 feet high in two channels, one 300 yards and the other only some 10 yards in width, when the water is low, as it was when I saw it.[2]

The rocks exposed in the falls were, so far as I was able to examine them, fairly uniform in grain, showing a reddish-brown felspar with a few dark blebs of quartz, apparently without a trace of schistose structure (M 7, Pl. V, fig. 3; specific gravity=2·58 to 2·63).

Under the microscope large crystals of plagioclase-felspar are seen, sometimes measuring as much as from 2 to 3 millimetres in diameter. In some cases they are traversed by a labyrinth of opaque or semi-opaque material, grey or reddish-grey by reflected light. This structure shows everywhere rectilinear outlines, parallel to the two directions of the lamellar twinning which is visible, in the clearer less-decomposed portions, between crossed nicols. The whole structure resembles masonry of stones of various sizes, but with their edges parallel in two directions. The extinctions in the zone of the macrodiagonal approach 20°, while the refractive index is distinctly lower than quartz, so that the felspar appears to be albite. Some felspars show only traces of twin lamellation, and still others, although full of small areas where the relative retardation is somewhat less than elsewhere (presumably on account of incipient decomposition), extinguish quite uniformly; they are, therefore, probably orthoclase.

There are a certain number of large porphyritic quartz-grains, which appear to have been attacked by the magma after their formation and rounded or eroded into cavities.

[1] 'On the river Trez Irmãos or Mutum Paraná,' says Col. Church ('The Route to Bolivia *via* the River Amazon' 1877, p. 188), 'I found the granite-rock cropping out at several points, but nowhere above the bank of the river to the point we ascended, a league up.'

[2] Col. Church (*loc. cit.* & Diary) states that his party caught sight of five little detached hills, from 80 to 150 feet high, forming a group about a mile east of Girão, but saw nothing farther eastward or north-eastward. One of his men told him that, some years before, he had penetrated beyond these hills 2 or 3 miles farther east, and that the country now and then had a gentle rise as high as his head, but was virtually a great plain extending northward and southward.

Hornblende is the principal and the only original, coloured constituent. The crystals are usually very irregular in shape, often branching. In many cases there is a border which apparently differs in composition from the interior, the latter representing an earlier period of crystallization. Sometimes the earlier crystal appears to have been worn, or altered into chlorite or other decomposition-products, before the later was deposited; in other cases, the centre appears to consist of flakes of hornblende, pseudomorphous after another mineral, perhaps augite. Occasionally the outer and inner portions are in crystalline continuity with one another, although the extinctions and other physical characters are different; but, in the majority of cases, the cleavage of the two seems to stand in no definite relation, so that they appear to be crystallographically independent, and yet the whole or the greater part of the outer shell extinguishes together and forms part of one crystal.

The birefringence of the two portions is different. In one case the rate of relative retardation in the section of the interior is about 20 thousandths (·020), but is rather less in the neighbourhood of the cleavage, where a certain amount of decomposition appears to have set in; while in the exterior hornblende the index is only 15 thousandths (·015). The angle of extinction with the vertical cleavages is very small in the interior portions, while it is sometimes as much as 32° in the exterior. The pleochroism is widely different, the centre changing from greenish-yellow to yellowish-green, while the outside shows different shades of bluish-green.

Numerous inclusions of apatite occur in the hornblendes and other porphyritic crystals.

The remainder of the rock consists of a fine-grained groundmass. It occurs more particularly surrounding the porphyritic quartz, and penetrating into its cavities. The chief constituent is quartz in minute, idiomorphic, bipyramidal crystals, containing occasional inclusions of apatite as well as small, colourless, isotropic, negative crystals, probably of glass. Felspars are also numerous, sometimes clear, and sometimes grey and cloudy from minute inclusions. They rarely show signs of twin-lamellation, but their refractive indices are usually well below that of Canada-balsam, and they are probably in most cases orthoclase. Micropegmatitic structure is visible, and in some cases it occurs as a border round the porphyritic quartz-crystals, with which the pegmatitic quartz is in crystalline continuity. Some comparatively-large grains of magnetite are surrounded by hornblende, no doubt contemporaneous with the exterior zone of the porphyritic hornblende, and there are areas where there is a poikilitic mixture of a pale-green hornblende, showing slight but distinct pleochroism, and felspar. In other places there are feathery aggregates of hornblende-microlites. Some ill-defined grey areas show a reddish appearance by reflected light.

The alteration of the interior of the porphyritic hornblendes and the corrosion of the quartz seem to indicate that they were formed

at a period long anterior to the crystallization of the groundmass. But, during each period of crystallization, the quartz seems to have been one of the earliest minerals to crystallize out.

This rock was analysed by Mr. George S. Blake, of the Scientific Department of the Imperial Institute, with the following result. The second column shows the proportions of the molecules of the different constituents, obtained by dividing the percentage by the molecular weight.

	Percentage composition.	*Molecular proportions.*
SiO_2	69·58	1·1597
Al_2O_3	13·72	·1345
Fe_2O_3	1·95	·0122
FeO	2·30	·0319
MnO	0·09	·0013
MgO	0·34	·0085
BaO	0·12	·0008
CaO	1·54	·0275
K_2O	5·19	·0552
Na_2O	3·57	·0576
S	0·19	·0059
F	0·07	·0026
H_2O above 100° C.	0·78	·0433
H_2O at 100° C.	0·52	
Less O replaced by F	−0·03	
	99·93	

From a consideration of the porphyritic minerals alone the rock might be classed as a quartz-hornblende-porphyrite (diorite-porphyry); but the orthoclase in the matrix and the alkalies shown by the analysis prove it to be more nearly allied to quartz-felsite (granite-porphyry). It probably forms part of a large intrusion. Rocks of similar composition and granitic structure have been described as granite, ægirine-granite, and granitite.

The rock from the Salto do Girão is rather poorer in alumina than most rocks with the same percentage of silica. It falls within the group (subrang) toscanose of the American quantitative classification.[1]

Some 3 miles below the Salto do Girão is another cataract, known as the Caldeirão do Inferno or Cauldron of Hell. Here the river, instead of narrowing, spreads out into numerous branches which flow in rocky channels. The prevailing rock is similar at first sight to that which is exposed at the Salto do Girão. It is mainly composed of bright-red felspar, with areas of grey rounded quartz, and here and there specks of a dark-green mineral.

Under the microscope (M 8) this rock appears to be fairly coarse, crystals of 1·5 millimetres in diameter being frequent. There is

[1] Whitman Cross, J. P. Iddings, L. V. Pirsson, & H. S. Washington, 'Quantitative Classification of Igneous Rocks' Chicago, 1903. This classification is so widely used in America that it cannot be ignored, but there appear to be grave reasons against its general adoption.

abundant microperthite much altered, being greyish by transmitted and yellowish-red by reflected light, and occasional small crystals of orthoclase showing Carlsbad-twinning, as well as much albite which is less altered. The latter contains numerous inclusions of a rodlike substance with extinction parallel to its length, which is the direction of vibration of the slower ray. It has a birefringence, or rate of relative retardation, of about 17 thousandths (·017), and is apparently a hydrous mica.

The quartz appears to be everywhere allotriomorphic, and is in many cases secondary, filling up cracks in other minerals. Biotite is also present, more or less altered into chlorite, and there is a little epidote. Veins of quartz occur in the rock.

The river now follows a winding course for some 50 or 60 miles through alluvial country, until another range of hills of crystalline rocks is passed at the cataract of Morrinhos, a name which signifies 'small mountains.'

Here are two rocky reefs, through which the stream forces its way. We landed at the second, and I was able to examine the rock (M 9). In hand-specimens it appears to be a fine-grained aggregate of brownish-red felspar. Under the microscope it is seen to be an acid granulite. The constituents have an average diameter of 0·25 mm. Many are well-rounded. Larger crystals occasionally occur. There is abundant plagioclase; the twinning, however, is in many cases but feebly developed. It is apparently albite. This felspar rarely exceeds the size that I have mentioned, but microcline, which is very common, sometimes occurs in crystals 1·5 millimetres in diameter. Microperthite is less frequent, but is occasionally found in comparatively-large crystals. There is much quartz, both in large individuals with irregular boundaries and in small rounded grains often minute, sometimes wedged in between the other crystals, and sometimes occurring as inclusions in them. In a few cases the grains exhibit traces of a crystalline outline, and the extinctions show them to be truly idiomorphic. There is a little green mica, representing biotite that has more or less passed into chlorite, and has an index of relative retardation of only about 8·2 thousandths (·0082). Magnetite has also resulted from the same decomposition. Some small sphenes are visible, as well as pyrites passing into hæmatite.

Some 15 miles below Morrinhos is the cataract of Theotonio, where the river passes a broad and lofty ridge in a contracted channel like that at the Salto do Girão.

There are two successive falls, the total drop being 25 feet. Each appears to correspond to a reef of hard rock that traverses the river. Below the second fall is another reef with a narrow opening, through which the stream flows with a strong current. When the water is low, as at the time of my visit, an expanse of bare rock is exposed to view, and in it the structure is well seen.

The prevailing rock-type appears megascopically to be a fine-

grained syenite with a brownish tint. Under the microscope the rock (M 12; specific gravity = 2·69) seems to be mainly composed of felspars ranging up to a millimetre in diameter, the commonest being an acid oligoclase with very fine twin-lamellation. Microcline and microperthite are also present, but there is very little quartz. There are traces of a pleochroic brown augite, now more or less decomposed. A green hornblende of later formation, with a maximum extinction of about 24°, appears to have been partly formed from the decomposition of the augite. Sphene, hæmatite, magnetite, chlorite, and epidote are also present, in most cases as alteration-products.

The syenite is intersected by a vein of coarsely-crystalline rock mainly composed of dull-red felspar, chiefly microperthite. There is a considerable quantity of quartz, interstitial or in large grains, occasionally occurring as rounded or idiomorphic inclusions in the felspar, and a little dark-green hornblende which is much decomposed. A number of well-developed zircons are also present.

There are also veins (M 11, Pl. V, fig. 4; specific gravity = 2·79 to 2·84) with a groundmass that is aphanitic to the naked eye, and small porphyritic crystals of felspar up to about a millimetre in diameter. On microscopical examination these prove to be an acid labradorite. Lath-like in section, they appear to form plates developed parallel to the brachypinakoid, or prisms parallel to the clinodiagonal. They are, to a considerable extent, altered into colourless decomposition-products. These are linear, blade-like, or lenticular in shape, as seen in thin sections, and usually fibrous and feathery in appearance. They often lie obliquely to the length of the felspar-sections. The direction of extinction corresponding to the vibrations with the less velocity is usually parallel with the length or fibrous structure. The birefringence is sometimes as much as 19 thousandths (·019). The refractive index appears to be higher than that of the felspar (say 1·557), or of a mixture of cedar-oil and monobromonaphthalene, with a refractive index of rather less than 1·57. It is, on the other hand, lower than that of the slower (ordinary) vibrations of the mineral allied to calcite, referred to below, or than that of monobromonaphthalene, 1·66. These determinations were made by the Becke method. In the case of the mixture and the monobromonaphthalene, a drop of the liquid was placed on the edge of the uncovered section that was free from Canada-balsam, and the Becke method was applied to the marginal crystals.

After treatment with hydrochloric acid and washing, the mineral was not stained by a solution of rhodamine, thus showing an absence of silicates yielding gelatinous silica when treated with acids. But, on drying in a hot air-bath, and then moistening with a solution of rhodamine, a stain was produced showing it to be a hydrous silicate.

From the foregoing characters I believe these alteration-products to consist of a hydrous mica, probably paragonite.

In a few cases a mineral, which is similar in general appearance, seems to have an oblique extinction, the angle between the length and

the direction of vibration of the slower wave-front being sometimes as much as 26°. It is possible that this is a secondary hornblende.

Porphyritic crystals of what once was olivine also occur here and there. They are altered partly to a mineral of the calcite-group, similar to that described below, and partly to another mineral more or less linear in section, with straight extinction and a birefringence rather higher than the alteration-products of the felspar above mentioned; it is not improbably phlogopite. Some serpentine may also occur, but the whole forms a complex of ill-defined minerals, the determination of which presents considerable difficulties.

The most remarkable feature of the rock is the presence of a number of spherical spaces up to 300 microns (0·3 mm.) in diameter. These are occupied by at least two different materials in more or less regular succession. Near the walls is a mass of irregular spherulites ranging up to a diameter of about 20 microns. They consist of radiating flakes of a pale-green mineral, with low birefringence and parallel or almost parallel extinction. The direction of vibration of the slower wave-front is parallel to the length of the sections of the flakes. The refractive index is well over that of the felspar and the mixture already mentioned, and lower than the monobromonaphthalene. The birefringence does not exceed 4 thousandths (·004). The mineral was strongly stained with rhodamine, both after drying in an air-bath and after treatment with hydrochloric acid. In spite of the deficiency in the pleochroism, I believe it to be a member of the chlorite group, probably the ferruginous species delessite. It presents a botryoidal contour towards the interior, which is filled with a transparent carbonate of the calcite-group. It was attacked by a fairly-strong solution of hydrochloric acid, but gave no stain with a solution of ferric chloride: this last reaction indicating the absence of simple calcium-carbonate.

Between the carbonate and the chlorite is a kind of granular selvage, representing the overlapping of the two.[1] The association of carbonates allied to calcite and chlorite is well known in hand-specimens. Occasionally, however, ill-defined patches with higher birefringence than the chlorite are seen. They may, perhaps, be flakes of hydrous mica similar to those noticed in the felspar.

These cavities appear to have been originally formed by the expansion of steam; subsequently, the chlorite formed round the inner surface, the centre of which was ultimately filled with carbonates. They seem to be analogous to the similar structures in pyromerides.

The groundmass of the rock presents some points of interest.

[1] It is interesting to note that, when the lower nicol is so placed as to allow the vibrations of the slower wave-front of the carbonate to pass, the irregularities of its upper surface are clearly seen, its refractive index being much higher than that of the balsam or oil with which it is covered; while, where the chlorite is overlain by the transparent carbonate, the boundary between them is but feebly marked, the difference between the refractive indices being comparatively small. On the other hand, when the faster vibrations with lower refractive index are allowed to pass, the surface of the carbonate appears smooth while the variations in the surface of the chlorite are well seen. In the former case, well-marked parallel fissures in the carbonate are sometimes visible which are more marked than ordinary cleavage-cracks.

The most conspicuous constituents are small felspars in lath-like sections, rather narrower in proportion to the length than in the case of the porphyritic crystals. They are generally less altered, although it is difficult to say why that should be so. Between them are numerous rodlike crystals, brownish-green in colour, and having usually oblique extinction. The angle between the direction of vibration of the slower wave-front with the length varies from 59° to 90°, according to the position of the section. The relative retardation is small, but this is largely due to the fact that the mineral, when lying parallel to the surface of the section, does not occupy the whole thickness. The pleochroism is feeble, the greatest absorption being usually, but not always, in the direction of the length. Approximately-rectangular sections appear to be fairly common, and have extinctions parallel to the diagonals. The mineral is probably a pyroxene. It resembles acmite in external form and in colour, but is allied in its optical characters to ægirine-augite. It appears to be altered in places, partly into opaque ferruginous products, partly into micaceous material similar to that derived from the alteration of the olivine.

Scattered about through the mass are numerous small crystals and rounded grains of magnetite, and probably ilmenite. The interspaces are filled with a glass-like material, which probably represents an original glass; it is usually feebly anisotropic in ill-defined bands, and may consist either of analcime or of a secondary glass. In it are numerous colourless needles, which appear to be identical with the larger similar crystals which I have identified as ægirine-augite. Similar needles are also occasionally found in some of the felspars.

The rock was analysed by Mr. G. S. Blake, with the following result:—

	Percentage composition.	*Molecular proportions.*		*Composition without carbonic acid and water.*
SiO_2	43·88	·7313		48·04
TiO_2	0·33	·0041		0·36
Al_2O_3	17·96	·1761		19·66
Fe_2O_3	4·07	·0254	=·1237 FeO	4·46
FeO	6·69	·0929		7·32
MnO	0·29	·0041		0·32
MgO	5·33	·1332		5·84
CaO	7·66	·1368		8·39
K_2O	1·37	·0146		1·50
Na_2O	3·62	·0584		3·96
S	0·12	·0037		0·13
F	0·04	·0021		0·04
CO_2	6·34	·1441		...
H_2O above 100° C.	1·38	·0767		...
H_2O at 100° C. ...	0·50	...		...
Less O replaced by F	−0·02	...		−0·02
Totals	99·56			100·00

The carbon-dioxide was determined, by taking the difference between the total loss on ignition and the amount of water present.

Subsequently, an analysis was made of that portion of the rock which is dissolved on boiling for a short time with 50 per cent. hydrochloric acid. The alkalies were not determined, and the iron

was estimated as ferric oxide, although much of it must have been present in the ferrous state.

	Percentages.	Molecular proportions.
SiO_2	0·68	·0113
Al_2O_3	6·17	·0605
Fe_2O_3	10·75	·1344 (of FeO)
CaO	4·06	·0725
MgO	1·91	·0477
CO_2	5·76	·1309
Total	29·33	

The material analysed appears to contain rather less carbon-dioxide, and more iron, than that dealt with in the general analysis. The silica taken up probably represents only a small proportion of that which is present in the silicates attacked by the acid, the rest remaining as gelatinous silica.

The chlorite (delessite) will account for most of the dissolved or gelatinous silica and the alumina, as well as for much of the iron-oxide and magnesia. Some of the iron-oxide is no doubt derived from the solution of the magnetite. The rest of the iron-oxide, magnesia, and lime, is derived from the carbonate, which is apparently a variety of ankerite. The labradorite and micas were, no doubt, also attacked to some extent by the acid.

The large amount of carbon-dioxide present shows that the rock has undergone considerable alteration, thus confirming the microscopical observations. Comparatively-little water is present, much less than if the olivine had undergone the usual process of serpentinization. Part of the bases appear to have been removed from the orthosilicates (olivine and the anorthite-portion of the labradorite), and accumulated as carbonates in the cavities. Some silica and alkalies may have been lost; but, on the whole, the chemical composition of the rock after the subtraction of carbonic acid and water will, I believe, represent very fairly its original composition.

According to the American classification, the rock would in that case be an andose. Its analysis is very similar to those yielded by basalts from Kilauea (Hawaii) and Ferdinandea Island (Graham Sunken Island) between Pantellaria and Sicily.[1]

	Basalt, Kilauea.		Basalt, Ferdinandea Id.		Theotonio. Without H_2O & CO_2.	
SiO_2	48·71		49·24		48·04	
TiO_2	1·81		...		0·36	
Al_2O_3	18·87		19·06		19·66	
Fe_2O_3	3·18	11·18	1·77	12·10	4·46	11·78
FeO	8·00		10·33		7·32	
MgO	4·85		5·00		5·84	
CaO	9·87		8·75		8·39	
K_2O	1·52		1·19		1·50	
Na_2O	4·15		3·89		3·96	
H_2O	...		0·63		Mn 0·32[2]	
	100·96		99·86		100·00	

[1] H. S. Washington, 'Chemical Analyses of Igneous Rocks' U.S. Geol. Surv. Prof. Paper No. 14 (1903) p. 282. [2] With S=0·13 & F=0·04; less O=0·02.

The original rock at Theotonio appears to have been a glassy aegirine-augite-olivine-basalt containing minute steam-cavities. These last furnish evidence that, at the time of the consolidation of the basalt, the syenite into which it was intruded was at no great distance below the surface, although there is every reason to believe that originally it solidified at a considerable depth. A considerable amount of erosion must have occurred, and a long period of time must have elapsed in the interval.

Another dyke (M 10) has a minutely-granular appearance in hand-specimens. Under the microscope, it proves to consist of a holocrystalline mixture of felspar and hornblende, the amount of the latter being about a fifth of that of the former. The predominant felspar appears to be microperthite, though microcline, microcline-perthite, and albite-oligoclase are also present. Most of the felspars vary between ·1 and ·2 millimetre in diameter, but occasional crystals reach or exceed a millimetre. Quartz is only represented by a few small sporadic grains.

There appear to be two generations of hornblende: the older has a green and yellow pleochroism, is more or less equally developed in all directions, and sometimes measures a millimetre across. The angle between the direction of extinction and the vertical axis reaches a maximum of about 18°.

The hornblende that crystallized out later shows pale and dark shades of green. It occurs in long needles or thin plates; these are sometimes independent, and exhibit sections which occasionally reach a millimetre in length, and sometimes are in crystalline continuity with the older hornblendes, although extinguishing at a lower angle, which does not appear to exceed 6°. In some cases, a number of these later hornblendes show parallelism with one another—being all connected together, so as to form a branching comb-like structure, of which one of the older crystals may constitute a part; the connection may not, however, be visible in the slide.

There are a few flakes of dark mica, and numerous small prisms of apatite. Sphene and magnetite are not uncommon.

The rock may be described as a fine-grained syenite rich in soda.

Except in the immediate neighbourhood of the river, the rock of the ridge that gives rise to the cataract is altered for a depth of several feet to an argillaceous material, probably laterite. A similar but less extensive change has taken place at some of the other cataracts.

Beyond the cataract of Theotonio we passed that of Macacos, but did not land, and before long reached the last cataract of the Madeira, that of Aroyá or Aroeira. It was at one time known as São Juan, but is usually referred to at the present day as the cataract of Santo Antonio, from the settlement of that name in the immediate neighbourhood.

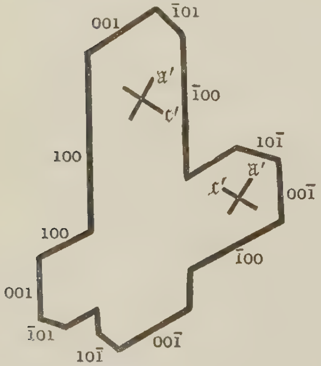
Here, as at the Caldeirão do Inferno, the river separates into a number of rocky channels which, after a fall of 4 feet, reunite in the pool below the cataract, where the steamers that ascend the river from the Amazon are moored.

The rock (M 13) is a coarse and handsome granite, with large red felspars occasionally showing Carlsbad-twinning and traces of perthitic structure. They sometimes measure 2 centimetres or more in diameter. There are smaller crystals of white felspar, abundant grey quartz, and a little black mica.

Under the microscope, the predominant felspar is seen to be a microcline-microperthite, in which the albite occurs either in more or less linear enclosures, or in broader rectangular or irregular patches connected by fine veins. Independent albite is found, and orthoclase is also present.

Quartz occurs in allotriomorphic masses constituting about a fifth of the rock. In some places, in the intervals between the larger crystals, there is an aggregate of small rounded grains, most of which are albite, although a little quartz also occurs, and the whole has a granulitic facies. There are a few crystals of biotite, and a little green hornblende with low angle of extinction and low birefringence; it sometimes occurs in micrographic relation with the orthoclase.

Fig. 3.—*Section of twin-crystal of allanite* (×51 *diameters*).



[Some of the smaller faces are imperfectly developed in the original.]

At one point are some small crystals of a tetragonal mineral with very low birefringence. They show well-marked lines of growth, and may be altered zircons. There is also an obliquely-cruciform twin of another mineral, apparently monoclinic (see fig. 3), which I believe to be allanite (orthite). At some points it is dark brownish-yellow and more or less turbid, at others it is pale yellow. The distribution of the colours is irregular, but the latter usually occurs as a border to the former. The angles seen in the section are near those of the combination of the forms 001, 100, and $10\bar{1}$ of allanite. The plane of twinning appears to be the face 101.[1] This is approximately the direction of vibration of the wave-front (a′) with greater velocity, and the position of extinction is almost identical in the two portions of the twin. The same direction is also that of greatest absorption, but the pleochroism is very feeble. The

[1] I believe that twinning on this face has not been previously recorded.

birefringence or relative retardation per unit of length amounts to 11 thousandths in the pale portions, and 18 thousandths in the darker. An examination of the figure in convergent light appears to show that the optic axial (binormal) plane is at right-angles to the plane of symmetry and approximately coincident with the plane of twinning; and that the acute bisectrix is in the plane of symmetry, and is the direction $\mathfrak{a}$ of vibrations giving the greatest velocity, while $\mathfrak{c}$, here the obtuse bisectrix, is the orthodiagonal. The optical sign is, therefore, negative. The section appears to be practically at right-angles to the optic axial plane, but is inclined to the plane of symmetry. The optical characters of the crystals agree with that described by Prof. W. C. Brögger, from Sognsvand (Norway), but differ from most of the others that have been examined, which have the optic axial plane in the plane of symmetry and the optic normal $\mathfrak{b}$ coinciding with the orthodiagonal.[1]

Below the pool, about half a mile from the foot of the cataracts, is another reef of crystalline rocks, which has now, however, ceased to interfere seriously with the flow of the river. The greater portion of the rocks that appear above the surface here consist of a fine-grained aggregate of grey quartz and pinkish felspar, with a few grains of black mica visible with a lens (M 14; specific gravity = 2·64).

In thin sections of the rock (M 14) the microscope shows it to be very similar in character, except in fineness of grain, to the rock of the cataract itself. There is a considerable amount of microcline and orthoclase, the latter having in many cases microperthitic inclusions of albite. Independent albite also occurs. A little biotite is present, showing strong pleochroism. It has dark areas round inclusions of apatite, but these are rather less pleochroic than the rest of the mineral. Small crystals of apatite also occur throughout the rock, and occasionally fluorspar is seen filling the interstices between other minerals; it is usually colourless, but sometimes shows violet patches.

At a few points there is a band of crushed material between adjoining crystals, but except for this and an occasional undulose extinction there is no indication of gneissose structure.

The average diameter of the principal minerals is about a third of a millimetre, but many crystals exceed a millimetre in diameter.

[1] Zeitschr. für Krystallogr. vol. xvi (1890) special part, p. 95. The character of the movement of the isogyr (the dark brush in convergent polarized light) is sufficient to show that the optic axial plane intersects the section, practically at right-angles, in the direction of the vibration $\mathfrak{a}'$; see F. Becke, 'Die Skiodromen' Tscherm. Min. & Petr. Mitth. vol. xxiv (1905) pp. 19, 26. This specimen also appears to agree with the Sognsvand variety, in having the pleochroism $\mathfrak{c} > \mathfrak{a} > \mathfrak{b}$ (namely, with the least absorption in the direction of the optic normal), while the other forms have $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

A number of traverses were made through a microsection, in order to estimate the volumetric composition of the rock by the method of Rosiwal,[1] who showed that the volumes of the different minerals are proportional to the sums of their intercepts on any line or lines drawn through the rock, if the number of minerals traversed be sufficient.[2] It was found that, out of a total length of 52·26 millimetres, the sums of the intercepts of the different minerals were as follows:—

Quartz	20·09
Orthoclase	13·37 } [3]
Microcline	9·35 }
Albite	6·22
Biotite	3·14
Apatite (estimated)	0·04
Fluor (estimated)	0·05
	52·26

These figures represent, therefore, volumetric proportions of the minerals. Classing microcline with orthoclase, and allowing for anorthite in the albite, the minerals are reduced to those shown in the first column of the next table. The figures in the second column represent the volumetric proportions in which they are present. Multiplying these by the densities (taking that of orthoclase as unity) given in the third column, we obtain the amounts in the fourth column, which represent the proportions by weight of the same minerals. In the last column these are recalculated as percentages.

	Volumetric proportions.	*Density (orthoclase=1).*	*Gravimetric proportions.*	*Percentage Min. Compos.*
Orthoclase	22·72	1·00	22·72	42·19
Albite	5·78	1·03	5·95	11·05
Anorthite	0·44	1·08	0·48	0·89
Quartz	20·09	1·04	20·89	38·79
Biotite	3·14	1·18	3·71	6·89
Fluor	0·04	1·24	0·05	0·09
Apatite	0·05	1·23	0·06	0·11
Totals	52·26		53·86	100·01

The chemical composition of the rock may now be calculated from that of the minerals. The composition of the biotite is assumed to be that of the mineral from El Capitan, Yosemite Valley, the analysis

[1] Verhandl. d. Geol. Reichsanst. 1898, pp. 143 *et seqq.*; 'The Quantitative Classification of Igneous Rocks' 1903, p. 204; J. P. Iddings, Journal of Geology, vol. xii (1904) p. 225; and Ira A. Williams, 'American Geologist' vol. xxxv (1905) p. 34.

[2] The line must, I need scarcely say, not be so traced as to pass through one class of constituents rather than another.

[3] These contain, in some cases, microperthitic inclusions of albite.

of which is given in column (*a*) of Table XIV of the 'Quantitative Classification of Igneous Rocks' Chicago, 1903.

Percentage Mineral Composition	*Orthoclase.* 42·19	*Albite.* 11·05	*Anorthite.* 0·89	*Quartz.* 38·79	*Biotite.* 6·89	*Fluor.* 0·09	*Apatite.* 0·11	*Percentage Chemical Composit.* 100·02
SiO_2	27·32	7·59	0·38	38·79	2·48	...	...	76·56
Al_2O_3	7·74	2·15	0·33	...	1·30	...	...	11·52
Fe_2O_3	...	...	...	...	0·39	...	...	0·39
FeO	...	...	...	...	1·02	...	...	1·02
MnO	...	...	...	...	0·06	...	...	0·06
MgO	...	...	...	...	0·68	...	...	0·68
CaO	...	...	0·18	...	0·04	0·06	0·06	0·34
K_2O	7·13	...	...	...	0·64	...	...	7·77
Na_2O	...	1·31	...	...	0·03	...	...	1·34
TiO_2	...	...	...	...	0·08	...	...	0·08
P_2O_5	...	...	...	...	...	...	0·05	0·05
F	...	...	...	...	0·02	0·04	trace	0·06
H_2O(combined)	...	...	...	...	0·18	...	...	0·18
Less O replaced by F	...	...	...	...	−0·01	−0·02	...	−0·03
	42·19	11·05	0·89	38·79	6·91	0·08	0·11	100·02

An analysis was subsequently made of this rock by Mr. G. S. Blake, with the following result :—

	Percentage composition.	*Molecular proportions.*
SiO_2	73·96	1·2351
TiO_2	trace	
Al_2O_3	13·10	0·1284
Fe_2O_3	0·74	0·0046
FeO	1·28	0·0178
MnO	0·04	0·0006
MgO	0·18	0·0045
BaO	0·06	0·0004
SrO	0·13	0·0013
CaO	0·70	0·0125
K_2O	5·05	0·0537
Na_2O	3·55	0·0573
P_2O_5	0·102	0·0007
S	0·041	0·0013
F	0·084	0·0044
H_2O above 100° C.	0·930	0·0517
H_2O at 100° C.	0·230	
Less O replaced by F	−0·036	
Total	100·141	

These figures correspond fairly well with the calculated composition, except in the case of the alkalies. The total molecular

amount of alkalies present is nearly the same in both cases, there being ·111 molecule in the actual analysis and ·104 in that calculated from the microscopic measurements; but, whereas there are ·054 molecule of potash and ·057 of soda in the former, the calculated amounts were ·087 and ·014. It is evident that the orthoclase and microcline contained a considerable amount of soda —either in microperthitic inclusions, or simply replacing potash in the orthoclase and microcline. The albite also appears to approach more closely to oligoclase than was supposed.

This is the typical composition of a granite fairly rich in soda and lime. Granitic rocks with a closely-similar composition have been described as granitite. It is included in the subrang liparose of the American classification.

Only some 20 yards or so on the up-stream side of the islands where the rock last described was exposed, is a small grey rock (M 15, Pl. V, figs. 5 & 6; specific gravity = 2·63 to 2·69), visible only when the river is low. In hand-specimens this presents a saccharoidal appearance like a crystalline limestone. In colour it shows various shades of dull green arranged in laminæ, so that it has a distinctly-streaky appearance. Under the microscope, it is seen to have in most places the characteristic structure of a granulite—consisting of an aggregate of small, more or less rounded grains of quartz and microcline with a considerable amount of felspar, which only occasionally shows twin-lamellation, but is probably in most cases albite. Some of the grains of quartz appear to be idiomorphic. The average diameter of the minerals is about 50 microns (0·05 millimetre). A few larger crystals of albite are met with, containing numerous needle-like inclusions, which have a birefringence of more than 11 thousandths. The faster vibrations of these inclusions are at right-angles to the length, and they are perhaps a hydrous mica.

There are numerous crystals of a pale-green granular augite, usually comparable in size and shape with the quartz and felspar described above, although a few may measure half a millimetre in diameter. They show little pleochroism. Some of the individuals, especially those sections which are near the clinopinakoid, are not quite dark in the position of extinction. This is presumably due to the dispersion of the bisectrices for the different colours. The birefringence reaches 20 thousandths.

There are also occasional crystals of sphene, which are strongly pleochroic, changing from a pale grey-green (something like that of the augite) to a dull orange. The birefringence exceeds 85 thousandths.

Hornblende occurs in small lath-shaped crystals or elongated plates, with an extinction-angle not exceeding 19°. It is strongly pleochroic, changing between a pale green, identical with that of the augite, and a deep blue-green.

In some places there are extensive aggregates of felspar, of much

larger size, measuring occasionally as much as a millimetre in diameter. They are separated by irregular jagged boundaries. At certain points they show the cross-lamellation characteristic of microcline, but in an ill-defined form; elsewhere the extinction often occurs in patches and streaks. The index of refraction is lower than that of quartz or albite, and there seems to be little doubt that these felspar-aggregates are to be referred to transitional forms between orthoclase and microcline. In these felspars, the smaller rounded constituents of the rock are embedded as in a glassy matrix, and at the same time recall the enclosures of blebs and rounded crystals of quartz (and occasionally microcline) in the felspars of the rocks of other cataracts.

An analysis by Mr. G. S. Blake showed the rock to have the following composition:—

	Percentage composition.	*Molecular proportion.*
SiO_2	69·41	1·1568
TiO_2	0·20	0·0025
Al_2O_3	12·83	0·1258
Fe_2O_3	1·06	0·0066
FeO	2·48	0·0344
MnO	0·12	0·0017
MgO	0·71	0·0177
CaO	4·73	0·0845
K_2O	5·25	0·0559
Na_2O	3·13	0·0505
H_2O above 100° C.	0·18	0·0100
H_2O at 100° C.	0·11	
Total	100·21	

It belongs to the subrang adamellose of the American classification, and corresponds in chemical composition to the alkali-granites of ordinary nomenclature.

(5) The Granulites and their Genesis.

It will be seen that, in one way or another, the great majority of the rocks of the cataracts are characterized by the presence of the small rounded crystals or blebs which are typical of the granulites. But the extent to which this structure is developed varies considerably from point to point. In some cases it prevails to the exclusion of any other, while in others it is only characteristic of a portion, sometimes but a small portion of the rock, the rest of which is formed by larger and unrounded crystals such as are found in a normally-developed holocrystalline rock. These appear to have been formed at a subsequent date, when the crystallization of the semi-consolidated rock continued and was completed under changed

conditions. Occasionally these later crystals appear to have pushed aside the granulitic element, as is sometimes the case in the rocks of Morrinhos and Santo Antonio, but more usually they have, in the course of their formation, enveloped the pre-existent granules which are now found embedded in them. In some cases, the granulitic phase appears to have been of comparatively-short duration; in others, the greater part, if not the whole, of the rock must have separated out before the conditions allowed of the development of the granitic structure. Sometimes the granulitic forms pass, by intermediate gradations, into those of the normal idiomorphic or hypidiomorphic granitic type; sometimes there is an abrupt change from one to the other.

In ordinary granitic rocks the quartz is the last mineral to crystallize, and has no crystalline boundaries of its own, being entirely allotriomorphic; but, throughout the granulitic element in the rocks which I am describing, a large proportion of the quartz shows idiomorphic boundaries, rounded it is true, but still recognizable. This is most clearly seen where the quartz-granules occur as inclusions in felspar, but it can be recognized even where the whole rock is made up of granulitic crystals.

Idiomorphic quartz is also found in many volcanic and dyke-rocks where the quartz appears to have crystallized out at least as early as the felspars. The most probable explanation of the difference in the order of crystallization in these and deep-seated granulitic rocks, is that it depends on the pressure to which the magma is subjected.[1] We may, therefore, reasonably suppose that the granulitic rocks of the cataracts crystallized at first under comparatively low pressure, and were subjected to long-continued earth-movements, which ground together and rounded the crystals during the course of their formation, or in the period immediately succeeding it; although the superior hardness of the quartz enabled it to retain, in some cases at least, traces of its crystal-outline. The finer débris resulting from the process of rounding must have been reabsorbed by the magma. Indeed, in some cases, as in the rock of the Esperanza Cataract, we have evidence of the quartz-crystals having been attacked and partly dissolved. This resorption may be explained by the increase of temperature which might be expected under the conditions that prevailed. For the prolonged earth-movements would themselves generate a considerable amount of heat, and the foldings in which they resulted would cause the accumulation of mountain-masses and a consequent rise in the isotherms. The cooling and crystallization of the still imperfectly-consolidated rock would then recommence, and proceed more slowly and under greater pressure than before, as well as under less-

[1] J. A. Cunningham, 'A Contribution to the Theory of the Order of Crystallization of Minerals in Igneous Rocks' Sci. Proc. Roy. Dublin Soc. vol. ix (1900–1902) p. 383. The presence of water may also have considerable influence, as has been pointed out by Prof. W. J. Sollas, Geol. Mag. 1900, pp. 295 *et seqq.*

disturbed conditions, so that a normal granitic structure would be developed in the minerals of the second stage.[1]

The haplite-dykes belong, no doubt, to the second stage of crystallization, although they are somewhat posterior in time; but most of the other dyke-rocks belong, I believe, to a much later period.

(6) The Black Coating of the Rocks of the Cataracts.

On the rocks of the island below Santo Antonio the black deposit referred to on p. 104 was well seen. A rough analysis, by Mr. G. S. Blake, of a little of this material scraped from the surface of specimen M 14 gave the following result:—

Insoluble in acids	SiO_2	6·6
	Residue (probably Al_2O_3)	9·3
Soluble in acids ...	MnO_2	54·1
	Fe_2O_3	6·5
	CaO	1·3
	MgO	0·0
Undetermined components, in all probability mainly water and organic matter		22·2
	Total	100·0

The state of oxidation of the manganese was not determined, but the material resembles psilomelane (hydrated manganese-dioxide), and it is in all probability a variety of that mineral. The presence of silica and alumina is no doubt due to part of the surface of the rock having been removed with the scrapings.

Similar black deposits have been described as occurring on the rocks of the Orinoco, the Upper Paraguay, the Nile, the Niger, and the Congo, especially in the neighbourhood of cataracts.[2]

Apparently manganese and iron-oxides are more soluble in river-water in the tropics than in colder countries. It is not clear that higher temperature of the water is alone sufficient. Probably there are organic compounds dissolved in the water, and the iron and manganese either occur as salts of organic acids or as carbonates,

[1] Similar inclusions in felspar of quartz with rounded idiomorphic boundaries occur in the granulites of Ceylon; see Dr. Ernst Weinschenk, 'Zur Kenntniss der Graphitlagerstätten' Abhandl. der Math.-phys. Classe der k. Bayer. Akad. der Wissensch. vol. xxi (1902) p. 298 & pl. vi, figs. 1–2; also 'Grundzüge der Gesteinslehre' pt. ii (1905) fig. 20, p. 51. For inclusions of quartz in hornblende, as in M 1 *a*, p. 97, see pl. v, fig. 4 of the former paper, and fig. 19, p. 50 of the latter.

[2] See a paper by MM. Lortet & Hugounenq, Comptes Rendus Acad. Sci. Paris, vol. cxxxiv (1902) p. 1091 (reviewed in the 'Geographical Journal' vol. xx, 1902, p. 655); 'The Geology of Matto Grosso' Quart. Journ. Geol. Soc. vol. l (1894) p. 98; also Dr. W. Kœrt, 'Geologisch-agronomische Untersuchung der Umgegend von Amani in Ostusambara,' Berichte über Land- & Forstwirthschaft in Deutsch-Ostafrika' vol. ii (1904) pp. 152 & 163.

In the latter case the rôle of the organic material would be confined to preventing the further oxidation of the manganese and iron, and consequent separation of carbonic acid. Ultimately, on the evaporation of the water on the surface of the rocks, this oxidation would take place, and the black crust would be formed. Such evaporation would obviously be of most frequent occurrence near cataracts in hot countries, where the rocks are repeatedly moistened by the waves and spray, and dried by the tropical sun. It is remarkable that in none of the analyses of the water of the Lower Amazon and its tributaries, given by Dr. Katzer, is there any mention of the presence of manganese.[1] Some interesting manganese-deposits on low ground are described (pp. 95–98), and may have an origin similar to that of the black coating on the rocks of the cataracts.

Since the above was written a valuable contribution to the subject has been made by Mr. A. Lucas, Chief Chemist, Survey-Department Laboratory, Cairo,[2] who has examined a large number of similar deposits on the rocks of the Nile Cataracts, as well as other feebler films on desert-rocks. He inclines to the belief that such deposits are an efflorescence from the rocks immediately beneath. This is an opinion to which I am unable to subscribe. Not only have I found large crystals of quartz and felspar coated equally with biotites or hornblendes, but I have seen in the Upper Paraguay crags of white sandstone covered externally by a jet-black coating which caused them to resemble basalt.

(7) Below the Cataracts.

The rocks of the island below Santo Antonio are the last crystalline rocks on the Rio Madeira. From this point in lat. 9° S. no rocks are exposed in the river-bed or banks, except argillaceous deposits usually more or less ferruginous, but sometimes nearly pure white. These may form banks 40 or 50 feet high at low water, but I saw nothing to lead me to suppose that they are the result of the alteration *in situ* of hard rocks. The Neogene deposits of Dr. Katzer may, however, be represented.

Three or four degrees farther to the eastward on the Tapajós, diorite and other crystalline rocks are said to occur.[3] Their presence on the Xingú, still farther to the east, has already been mentioned (p. 88). Farther north Palæozoic rocks are met with, extending westward to the margin of the basin of the Madeira between 5° and 6° lat. S.,[4] following the line of elevation on the

[1] 'Grundzüge der Geologie des Unteren Amazonasgebietes' 1903, p. 48.
[2] 'The Blackened Rocks of the Nile Cataracts & of the Egyptian Deserts' Cairo, 1905.
[3] F. Katzer, *op. supra cit.* pp. 234 & 236.
[4] *Ibid.* p. 170.

south of the Amazonian syncline. No doubt these rocks would be found below the alluvium of the Lower Madeira.

IV. Summary.

The crystalline rocks of the cataracts of the River Madeira and the lower waters of its tributaries are part of a ridge, with a north-westerly and south-easterly strike similar to that of the Andes in the same latitudes. This strike, which is especially prevalent in Equatorial regions, is probably due to the same causes as those that have resulted in the eastern position of the land-masses of the Southern Hemisphere as compared with the Northern.

With the exception of comparatively-recent alluvial deposits, and a few pebbles of chert of marine origin but uncertain date, only crystalline rocks are met with. They all appear to be igneous, mostly massive in character, though some dyke-rocks occur. In places they are typical gneisses, and they are often banded; but in some cases they show no signs of foliation. The prevailing type is acidic, with a considerable proportion of alkalies, especially soda; but some of the dyke-rocks are distinctly basic in character. The more acid rocks are usually fine in grain, and are often granulitic in structure. In most cases the quartz seems to have crystallized out before the felspar. The causes of these characters are briefly discussed.

The occurrence of andalusite of a chiastolite-type as an inclusion in a felspar is noted, as well as an unusual type of allanite. An altered basalt is described, containing minute concentric structures allied to those of a pyromeride.

Above and below the region of the cataracts is a wide expanse of alluvial country, either of recent or later Tertiary date.

In conclusion I wish to express my obligations to Prof. Bonney, Sc.D., F.R.S., who kindly examined many of the rock-sections; also to Dr. G. T. Prior, of the British Museum (Natural History), and others, for criticism and suggestions during the preparation of this paper. I must also acknowledge my indebtedness to Mr. Thomas Crook, F.G.S., for valuable assistance in photographing the microscope-sections shown in Plate V.

EXPLANATION OF PLATE V.

Fig. 1. Section of granulitic gneiss from Lages, Rio Madeira, above the confluence with the Beni; magnified 21 diameters. Ordinary light; showing acid plagioclase, quartz in blebs or rounded idiomorphic crystals, biotite, and micrographic structure. (See p. 98.)

2. The same in polarized light, between crossed nicols. The plagioclase is seen to contain inclusions of orthoclase and quartz.

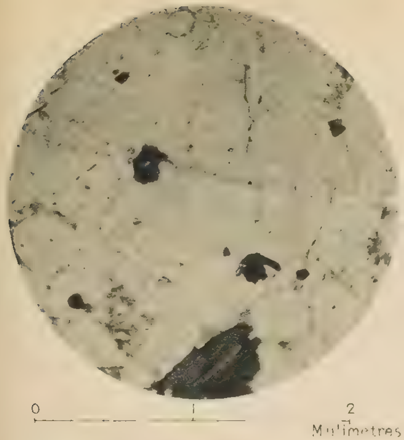
Fig. 3. Section of granite-porphyry from the Salto do Girão, Rio Madeira; magnified 17 diameters. Ordinary light; showing corroded quartz, decomposed albite, and groundmass. (See p. 105.)

4. Section of basalt from Theotonio, Rio Madeira; magnified 51 diameters. Polarized light without analyser; showing three spherical spaces filled with chlorite and a lime-magnesia-iron carbonate, a portion of a decomposed labradorite-crystal, and groundmass. (See p. 109.)

5. Section of pyroxene-granulite from the island below Santo Antonio, magnified 24 diameters. Showing pyroxene, sphene, and hornblende; the clear material is felspar and quartz. (See p. 118.)

6. The same in polarized light, between crossed nicols. Showing, at some points, only granules of the different constituents already mentioned, at others shadowy felspars in which the granulitic constituents are embedded as in a groundmass.

1.



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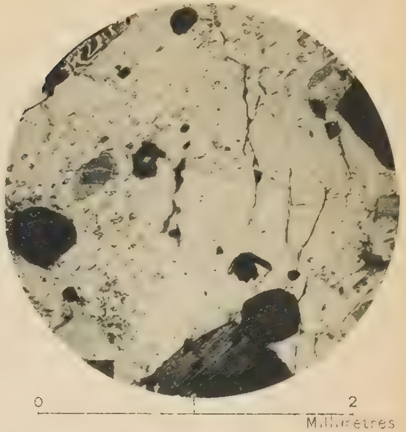

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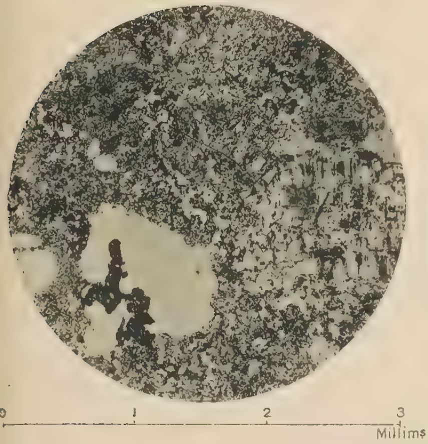

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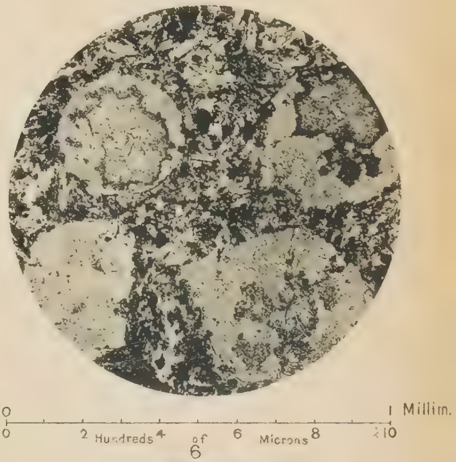

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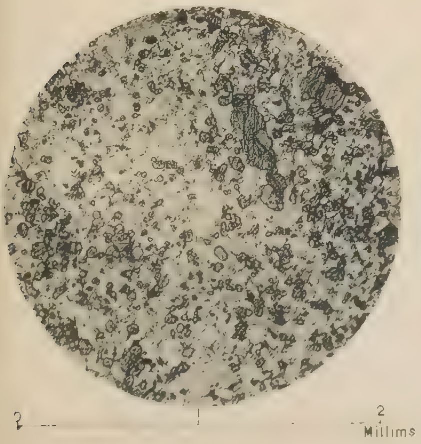

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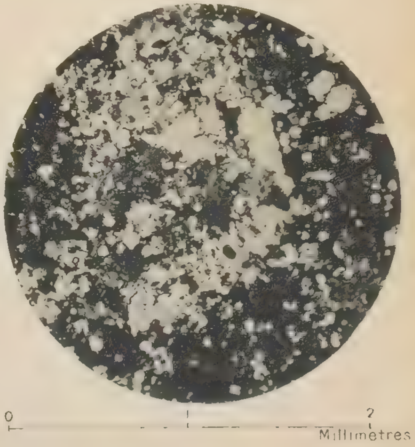


ROCKS FROM THE RIO MADEIRA, &c.

J. W. E. & T. C., Photomicro. *Bemrose, Collo.*

7. *On* Footprints *from the* Permian *of* Mansfield (Nottinghamshire).

By George Hickling, B.Sc. (Communicated by Prof. W. Boyd Dawkins, M.A., D.Sc., F.R.S., F.S.A., F.G.S.
Read January 10th, 1906.)

It is the object of this brief communication to call attention to a series of footprints discovered so long ago as October 1897 by Mr. Francis Holmes, of Leicester, the description of which has been delayed by the lamented death of the geologist to whom we owe their preservation, the late Mr. James Shipman, F.G.S., of Nottingham.

I. Notes on the Strata.

These impressions were obtained from the Rock-Valley Quarry, Mansfield, in the Permian rocks north-east of the town, some 500 yards from the Permo-Triassic boundary, where they are overlapped by the Lower Mottled Sandstone. The rock which is here quarried is a lenticular mass of sandstone intercalated in the Magnesian Limestone, described by Aveline in the Geological Survey-Memoir on Sheet 82 S.E. 2nd ed. (1879) pp. 10–12, as a locally-sandy type of the limestone, passing laterally into the normal type. The stone is here yellowish-red in colour, becoming almost white on the opposite side of the town. It is by no means pure sandstone throughout, but contains irregular bands of 'bastard,' a term used by the quarrymen to indicate a calcareous sandstone. Every gradation may be found between a pure sandstone and the almost pure limestone.

The general succession in this quarry appears to be as follows, in descending order, though all the beds vary greatly in thickness :—

	Feet.
1. Limestone	15
2. Laminated 'bastard' 3. Coarse sandy 'bastard'	10
4. Sandstone, with bands of 'bastard'	20
5. Limestone	?

Current-bedding is developed on a large scale, some of the beds of sandstone having an apparent dip of as much as 25°, although the true dip would appear to be quite trifling. Examples may be seen, too, of contemporaneous erosion.

A detailed examination of the Permian round Mansfield led Mr. Shipman to conclude that these intercalated sandstones probably were formed as sandbanks off the mouth of some river flowing from the then newly-formed Pennines, and that the actual shore-line lay some 3 or 4 miles to the west of the town. To these conclusions he was led mainly by the generally-lenticular form of the deposits, the varying coarseness of the sediments, and the nature of the current-bedding.

II. Mode of Occurrence.

These impressions were found on slabs from the middle of Bed No. 4 (in the foregoing section, p. 125). When first seen by Mr. Shipman, on October 21st, 1897, they were still *in situ*; and we learn from his notes, made on that occasion, that they formed two double rows, approximately parallel, which crossed the slab in a direction very nearly from west to east. The longer row could be traced for about 7 feet. The shorter series was by the side of the longer one at a distance of a yard, and was only to be followed satisfactorily for a little more than 2 feet.[1] Of these impressions, nearly the whole of the longer series is preserved on a large slab in the Free Public Museum, University College, Nottingham, and the prints of the right side of the shorter series are in the Manchester Museum, Owens College. The left side of the latter series, and a few imperfect impressions from the former, have not been preserved. The overlying slab, with the natural casts, was used for commercial purposes before the prints were noticed.

III. Description of the Impressions.

A comparison of the slabs preserved at Nottingham and Manchester respectively at once reveals the fact that both sets of impressions were made by the same species of animal, although a very slight inferiority in size of the Manchester prints (which may be estimated by the stride measuring 8 inches, as against $8\frac{3}{4}$ inches in the Nottingham examples) would seem to point to their being due to different individuals. Practically, however, the principal measurements will apply to both series. The chief of these are as follows:—

		Inches.
Pes:	Length	$3\frac{2}{3}$
	Width (tip of digit I to tip of digit V)	$2\frac{3}{4}$
Manus:	Length	$3\frac{1}{6}$
	Width	$2\frac{3}{8}$
Average width between middle of right and left pes		$5\frac{1}{2}$
Do. do. do. do. do. do. manus		$7\frac{1}{2}$
Length of stride[2] (Nottingham slab)		$8\frac{3}{4}$

The general character of these impressions will be seen much more clearly from the accompanying figures (pp. 127 & 128) than from any amount of description which might be given. They are, for the most part, very badly preserved; and only in a few cases could they be definitely recognized as footprints, had they been found separately. The individual prints are characterized by their 'stumpy' form, by the well-marked heel, 'very like the heel of a boot

[1] I have since learned that more of both rows was subsequently exposed, but the other portions are not preserved.

[2] 'Stride' is here taken as the distance between successive prints of the same foot.

in form,' and by the comparatively-slender digits—more slender, I believe, than one would at first conclude from a casual glance at the photographs—of which the fifth is set back and turns outwards and forwards. As regards the presence or absence of claws, it is impossible to speak with absolute certainty, but the pointed endings of the impressions of the digits, in some cases extending forwards into slender scratch-like streaks, make their presence very probable. But of much greater interest is the very smooth convexity of the surface of the stone between the impressions of the digits, seen as a rounded concavity in the plaster-casts. There appears to be but one conceivable explanation of this feature, namely, the presence of a membrane between the toes. Unfortunately, the state of preservation is not sufficiently good to enable one to speak with confidence; but it must again be regarded as probable that the animal was web-toed. There is no indication of the number of phalanges in the digits. It may be added that the pes was undoubtedly pentadactylate and the manus probably so, although in the latter case I have been unable to discover a really-indubitable impression of the first digit. It seems to be represented by a kind of stump on the casts photographed.

Fig. 1.—*Photograph of footprints on the slab preserved in the Free Public Museum, University College, Nottingham.*

[Total length = slightly over 5 feet.]

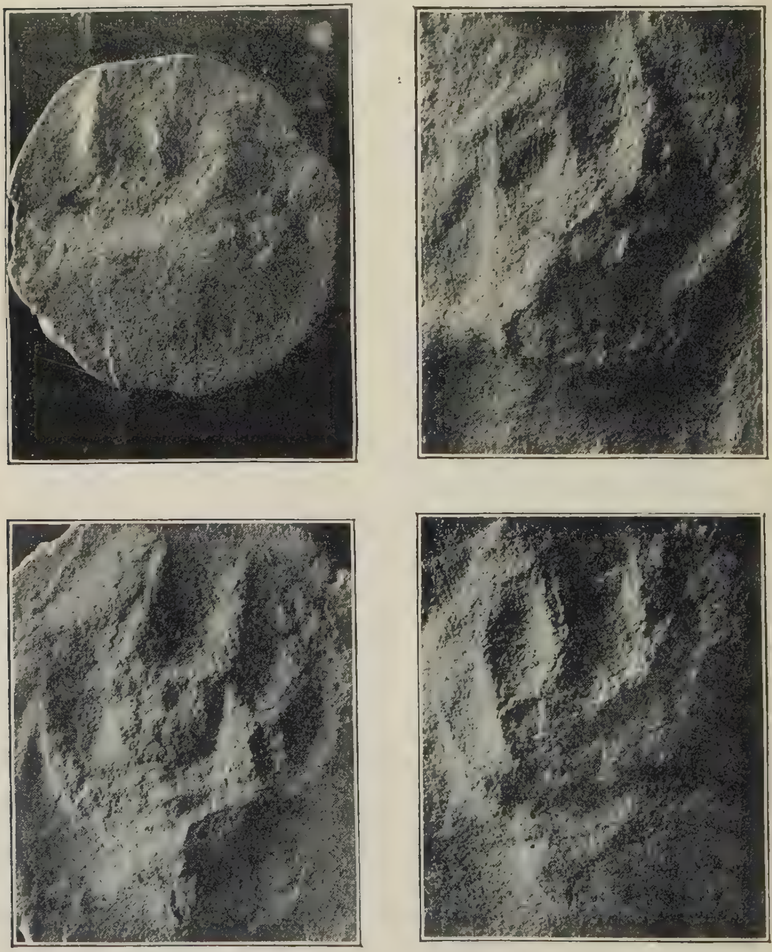
Regarding the general arrangement of the prints in the track, allusion may be made to their close succession, to the wide separation of the right and left sides, and to the fact that the fore feet were more widely separated than the hind feet.

IV. Conclusions.

It now remains to consider the import of these impressions. So far as I have been able to determine, they do not entirely agree with any that have been previously described, either from the Permian or from the Trias. One's first idea is that they may, perhaps, be associated with the cheirotheroid prints from the latter formation—

Fig. 2.—*Plaster casts of the fore and hind foot of the right side from the Manchester slab, and of the fore and hind foot of the left side from the Nottingham slab.*

Right fore foot. *Left fore foot.*



Right hind foot. *Left hind foot.*

[The photographs are on the scale of $\frac{6}{11}$ approximately.]

an idea which might seem to receive considerable support from the out-turned fifth digit. On more careful examination, however, the supposititious association has to be abandoned. Cheirotheroid prints have the following characteristics:—Of the five digits, II, III, and IV are stout and strongly marked, the fifth is set back and curves outwards and backwards, while the first is much less conspicuous and quite commonly leaves no impression. There is never any trace of a heel, except in the aberrant *Cheirotherium Herculis*, and in some cases impressions of the digits alone are seen. There is no trace of any interdigital membrane. The stride was long, commonly about a yard, and all the impressions are nearly in one line, indicating an animal very well adapted for rapid progression on land. The fore feet were greatly reduced, and nearly the whole weight was supported by the hind limbs.

Very different are the characters of the impressions with which we are concerned here. They were made by an animal emphatically plantigrade. The stride was very short, and the gait that of a clumsy animal ill-fitted for walking. The fore feet were only a little smaller than the hind feet, and the weight of the body was much more evenly distributed. The digits were comparatively slender, and were probably joined by a web. Even the fifth digit, though modified, was much less so than in *Cheirotherium*. In passing, it may be remarked that this modification of the fifth digit seems to have been a fairly-common feature among the animals of Permian and Triassic times, and some explanation of its meaning might be interesting.

The only previously-described impressions that I have been able to find, which do present any close resemblance to these Mansfield prints, are those from the Upper Permian of Thuringia, of which an account has been written by W. Pabst.[1] The footprints there described under the name of *Ichnium acrodactylum* agree in a striking manner with those here described. In size, in general form, in the arrangement of the digits, and in the general arrangement of the track no decided distinction can be found. The individual prints, however, differ markedly in one respect, namely, in the much greater stoutness of the digits in the Thuringian form, so that between the first four digits no marked interspaces appear. The digits are also somewhat longer. To some extent, though not entirely, these differences may be accounted for by the fact that the Thuringian prints are more deeply impressed than the Mansfield prints.

Two other points serve to distinguish definitely these two sets of tracks: the first, that the difference in size between manus and pes in *Ichnium acrodactylum* is still less marked than in our own prints; the second, that the stride of the former is much longer—approximately 12 inches. The feet (at least, the hind feet) were slightly less than in the Mansfield form. Yet, despite such differences, the general resemblance is so strong that one can scarcely do other than suppose a real relationship between the Thuringian animals and those of our own ancient shores.

[1] Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xlix (1897) pp. 701 *et seqq.*

If Mr. Shipman's conclusions regarding the mode of formation of the rocks which yielded our impressions are sound (see p. 125), we may assume that the animal responsible for them was wandering on a sandbank some distance from land. In view of the further facts that it was probably web-footed, and that it certainly had an awkward gait, it would seem reasonable to assume that it was amphibious in habit. At least no further evidence on this point could be expected from its footprints.

The two brief visits which I have as yet been able to pay to the Rock-Valley Quarry have sufficed to show that footprints are really abundant there—mostly in a very imperfect state of preservation, but including some quite good impressions. In the course of less than two hours' search altogether, I have been able to distinguish several (at least four) distinct types of impression, which undoubtedly represent different types of animals and cannot be attributed by any chance to differences of imprint.[1] These other forms I hope to be able to describe in a future communication, after further search of the deposits has been possible. Meanwhile, I may note that some of them bear a marked resemblance to those found by the late Mr. G. Varty Smith in the Permian sandstones of Penrith.[2]

The abundance and variety of the footprints in this quarry are of considerable interest, in connection with the recent discovery of a rich vertebrate fauna in the Permian of Russia.[3] The knowledge of the existence of quite a varied assortment of reptiles at that period—Anomodonts, Theriomorphs, Rhopalodonts, and probably Deinosaurs—widens considerably the range of beasts which we might expect to have inhabited our own shores. Formerly, the only forms to which we could attribute such footprints as those here described were the Labyrinthodont Stegocephalia, which group, indeed, satisfied very well the general characters indicated by the impressions. But, in view of Prof. Amalitzky's discoveries, we should keep watch for indications of the higher forms. Should footprints be discovered in the bone-bearing deposits of Russia, they might, with some certainty, be referred to the animals which made them. Then the prints in our own rocks might receive their interpretation. Meanwhile, this communication may perhaps serve its most useful purpose by drawing the attention of local geologists to the existence of these sandbanks in the Magnesian Limestone—the one at Mansfield is unlikely to be an isolated example—and to the fact of their containing traces of perhaps the most interesting fauna with which the vertebrate palæontologist has to deal.

[1] [Not less than six distinct forms have now been found.—*March 15th, 1906.*]

[2] See Quart. Journ. Geol. Soc. vol. xl (1884) p. 479. Still more interesting is the close resemblance, if not identity, of one of these forms with that described by Huxley from the Elgin Sandstones, and figured in Geol. Surv. Monograph iii, pl. xiv (1877).

[3] See V. Amalitzky, Comptes Rendus Acad. Sci. Paris, vol. cxxxii (1901) p. 591.

In closing this brief note I wish to express my sincere thanks to Prof. J. W. Carr, F.G.S., University College, Nottingham, for the photograph forming fig. 1 and for two of the casts shown in fig. 2; and to Mr. H. C. Beasley, of Liverpool, from whom personally and from whose writings I have received the greatest assistance.

Discussion.

Prof. Boyd Dawkins pointed out that, as no footprints had previously been found in the undoubted Permian of this country, the finds with which the Author's paper dealt were naturally of extreme interest. The footprints were probably made by an amphibian, analogous to the amphibian types recorded from the Permian of the Continent.

8. *The* Clay-with-Flints; *its* Origin *and* Distribution.

By Alfred John Jukes-Browne, B.A., F.G.S. (Read January 10th, 1906.)

[Plate VI—Sections.]

Contents.

I. Definition and Theories of Origin.

The peculiar deposit which has been termed 'Clay-with-Flints' is well known to most English geologists, as occurring in sheets or patches of various sizes over a large area in the South of England, from Hertfordshire on the north to Sussex on the south, and from Kent on the east to Devon on the west. It almost always lies on the surface of the Upper Chalk, but in Dorset it passes onto the Middle and Lower Chalk, and in Devon it is found on the Chert-Beds of the Selbornian Group.

The existence of a red clay full of flints, lying as a soil or deposit on the surface of the Chalk, was well known to geologists in the middle of last century, such as Trimmer, Lyell, and Prestwich; and some appear to have regarded it as a residue derived from the solution and disintegration of the Chalk, but Joshua Trimmer in 1851 maintained that it and the other 'soils which cover the Chalk of Kent' were the result of aqueous transport.[1]

It was not until 1861 that it was described as a special accumulation or aggregation by Mr. Whitaker, under the name of Clay-with-Flints[2]; and not until 1864[3] that he ventured to suggest an explanation of its formation. His belief was and still is that

> 'the Clay-with-Flints is of many ages, and may be forming even at the present day, and that it is owing in great part to the slow decomposition of the Chalk under common atmospheric action.'

He holds that, as many Chalk-districts have been exposed to the action of rain for thousands of years, much of the Chalk has been carried away in solution, leaving the flints and the insoluble earthy and ferruginous matter. He remarks that

> 'To these would be added the clayey and loamy wash from the Tertiary lands, and the remains of beds of that age left in pipes and hollows of the Chalk . . . .

[1] Quart. Journ. Geol. Soc. vol. vii (1851) p. 34.

[2] 'Geology of Parts of Oxon & Berks' Expl. of Sheet 13, Mem. Geol. Surv. p. 54.

[3] 'Geology of Parts of Middlesex, Herts, &c.' Expl. of Sheet 7, Mem. Geol. Surv. p. 64.

The clay and flints left by the dissolution of the Chalk would be present almost everywhere; whilst the loamy materials that would be formed from the lowest Tertiary beds would most likely be more local.'[1]

In 1865 Mr. Thomas Codrington, describing parts of Wiltshire in which this Clay-with-Flints was prevalent, had come to a somewhat different conclusion. He accounted for the presence of the unworn flints and for the peculiar disposition of the deposit in the same way as Mr. Whitaker had done; but he thought that the original presence of an overlying deposit of clay or loam was essential to its formation. He writes:—

'Everything seems to indicate a quiet subsidence of the overlying bed into irregularities in the dissolving Chalk. Everything here also favours the supposition that the origin of the Clay-with-Flints is to be ascribed to the gradual dissolving away of the Chalk-with-Flints under a capping of drift brickearth. . . . . The Clay-with-Flints must underlie the brickearth, when the latter is present, but the whole of it (that is, the brickearth) may be absorbed into the Clay-with-Flints.'[2]

Lastly, Charles Darwin, writing in 1881, does not refer to Mr. Whitaker's explanation, but takes it for granted that the whole of the red clay (as well as the flints) was simply the insoluble residue left by dissolution of the Chalk, without the addition of any extraneous matter.[3] It is clear, however, from the remarks which he makes, that he was puzzled to account for the absence of such a thick residue in many places where it might be expected, and also for its thickness in places where analyses proved that the underlying Chalk contained a very small amount of earthy matter.

Of these three explanations, I believe that Mr. Codrington's, so far as it differs from Mr. Whitaker's, comes nearest to the truth, for I think that he was right in asserting that the argillaceous part of the Clay-with-Flints has been derived from Tertiary material and not from the Chalk. I dissent from Mr. Whitaker's view, because he contends that the bulk of the clay came from the Chalk, and only admits a local admixture of Tertiary material. Lastly, I consider that Darwin was still further from the truth, because he imagined that the whole deposit had been derived from the Chalk. It is only fair, however, to say that Darwin does not appear to have studied the distribution of the Clay-with-Flints over any large area, and was only incidentally concerned with the manner of its formation.

What may be termed the 'Chalk-residue theory' has held the field in this country for many years, but during the last decade geologists have been losing faith in it; consequently, it seems only right and fitting that the other side of the case should be presented, and discussed more fully than Mr. Codrington had the opportunity of doing. I propose therefore to state the reasons which have induced me to abandon the faith in which I was educated, and I

[1] 'The Geology of London' Mem. Geol. Surv. vol. i (1889) p. 282.
[2] Wiltsh. Arch. & Nat. Hist. Mag. vol ix (1865) pp. 180–81.
[3] 'The Formation of Vegetable Mould, &c.' 1881, pp. 137–39 & pp. 298–300.

trust that my old friend Mr. Whitaker will pardon me for holding a brief against him.

Some of the facts which militate against the Chalk-residue theory have been already advanced by Mr. Clement Reid and by myself in the Annual Reports and Memoirs of the Geological Survey. Some of these will be quoted in the sequel, but data for a more detailed consideration of the whole subject are now available, and consequently it seems desirable that the whole case should be stated as clearly as possible in one paper.

II. Composition of the Clay-with-Flints.

The material was defined by Mr. Whitaker as

'a deposit of stiff brown and reddish clay with large unworn flints, that occurs over the higher parts of the Upper Chalk-tract.'[1]

He also noted that, at its base, there is often a layer of black clay, a few inches thick, which contains black-coated flints. He distinguishes the true 'Clay-with-Flints' from the loam or brickearth by which it is often overlain, admitting that the latter has been mainly derived from the detrition of the Reading Beds, that it often contains large unworn flints, and that it frequently passes so completely into the Clay-with-Flints that it is difficult to draw a line between them.[2]

I will, however, confine myself to the Clay-with-Flints, as defined by Mr. Whitaker, and pass on to the important point of its composition and contents.

In its typical development on the west and north-west sides of the London Basin, the material is generally a stiff, unctuous, brown or reddish-brown clay, usually without any visible admixture of sand, but containing unworn flints the outer surfaces of which are generally stained brown. Where sections of such clay are seen below brickearth, the flints do not generally form more than half the bulk of the deposit; but, where there is a surface-spread of Clay-with-Flints, the upper portion of it contains more flints than clay, and is in fact an angular flint-gravel. This is doubtless a consequence of the washing-away of the fine clay by the rain.

Mr. Whitaker remarks (*op. cit.* p. 282):

'Besides the unworn flints, there are also sometimes pebbles of flint and of quartz, as well as, more rarely, pieces of old rocks.'

Again, he mentions the occurrence near Remenham, in Berkshire, of green-coated flints from the base of the Reading Beds, pebbles of quartz and quartz-rock, and a few small lumps of ironstone.

Mr. Whitaker, however, does not mention the fact that broken angular flints are very common ingredients. The only passage from which it would appear that he was aware of that fact is that

[1] 'The Geology of London' Mem. Geol. Surv. vol. i (1889) p. 281.
[2] *Ibid.* p. 288.

at the bottom of p. 283 (*op. cit.*), where he speaks of 'the unworn and often unbroken character of the flints' as being against the theory of transport. It is true that both kinds of flints are unworn, but there is a great difference between entire flint-nodules (as they occur in the Chalk) and angular pieces of broken-up flints.

I have not had a sufficiently-wide experience of Clay-with-Flints in the South of England to be able to assert that angular flint-fragments are everywhere abundant in it. I can only testify to their occurrence in the counties of Hertford, Bedford, and Buckingham, and again in Dorset. Mr. H. J. Osborne White, however, who has special acquaintance with the deposits overlying the Chalk in the counties of Buckingham, Oxford, and Berkshire, informs me that he considers the angular flints to be generally more numerous than the unbroken flint-nodules, and that he knows of exposures where the latter are rarely found and where all the flints usually to be seen are angular. Lastly, Mr. Clement Reid, writing of the country around Salisbury,[1] describes the clay as containing 'unworn or shattered flints,' by which I suppose he means unbroken and broken flints.

Charles Darwin, when describing the Clay-with-Flints near Down in Kent,[2] remarks that the flints are often broken though not rolled or abraded, and that the elongate flints are commonly found 'standing nearly or quite upright in the red clay,' a position which he ascribes to the downward movement of the mass from higher to lower levels. He also incidentally mentions that the flints in the clay 'form almost half its bulk.'

With regard to the unbroken flints, which have mostly been derived directly from the Chalk, Mr. Osborne White tells me that, in his experience, they seldom occur in any number, except in the bottom-layer of the clay at its junction with the Chalk, and in pipes or funnels which penetrate into the Chalk. Their greater abundance in such hollows is not surprising, since these are evidently spots where solution has taken place more extensively than elsewhere.

Another point requiring notice is the frequent occurrence of green-coated flints, derived from the base of the Reading Beds. On this matter Mr. White writes:

'I feel sure that green-coated flints are quite as common in the Clay-with-Flints as one would expect them to be.'

It is moreover possible that the black-coated flints, which are also common where the clay is black, may be such flints coated or stained black by oxide of manganese.

Mr. Clement Reid, describing the Clay-with-Flints in Sussex,[3] says that it consists of Eocene material mixed with a certain

[1] Expl. of Sheet 298, Mem. Geol. Surv. 1903, p. 64.
[2] 'The Formation of Vegetable Mould, &c.' 1881, pp. 138–39.
[3] 'Geology of Eastbourne' 1898, p. 10, and 'Geology of Chichester' 1903, p. 38, both memoirs of the Geological Survey.

proportion of flints, and he states that it always contains a large percentage of rounded quartz-grains, such as could not be derived from the Chalk below. Again, among its contents in the country north of Chichester he mentions the occurrence of flint-pebbles, green-coated angular flints, sarsen-stones, and quartz-sand, these 'and probably most of the clayey matrix, being of Eocene origin.'

Mr. Reid also makes the explicit statement that

'in this part of the Downs (near Chichester) it is confined to areas over which Eocene deposits may have spread within comparatively recent times; it is sometimes very difficult to decide whether a particular patch should be called slightly-disturbed Eocene, or mapped as Clay-with-Flints.' (*Loc. supra cit.*)

With the truth of this statement, as applied to other districts, I shall deal more fully in the sequel.

The same observer, describing the deposit as developed near Salisbury,[1] writes that 'parts of it are mainly composed of Eocene material,' and 'other parts are derived in large measure from the Chalk below.' He adds:

'Everywhere, however, there is a considerable admixture of material that cannot have been derived from the strata immediately below. We find in it, for instance, Chalk-flints belonging to zones which only outcrop some distance away on higher ground. It also contains pebbles derived from Tertiary deposits, which cannot have rested directly on the Chalk in that neighbourhood. On washing the matrix we obtain a sandy residue consisting of rounded grains of quartz, such as could not have been derived from the Upper Chalk.'

Again, in Dorset the proportion of material that must have been derived from the Eocene is still larger, and Mr. Reid observes:

'At least half the deposit consists of rolled stones and rounded quartz-grains. . . . Even of the angular material, a close examination shows that a considerable proportion must be derived from the gravelly base of the Eocene deposits, in which angular flints usually abound.'[2]

He asserts, indeed, that

'over the area now under consideration solution of the Chalk and accumulation of the insoluble matter will not produce anything approaching in composition to the Clay-with-Flints.' (*Loc. cit.*)

My own observations in Wiltshire and Dorset confirm those of Mr. Reid, especially on the point that, where the deposit is most argillaceous and most essentially a Clay with flints, it is still obviously and largely composed of Eocene material.

With regard to the finer portions of the Clay-with-Flints, it will be noticed that Mr. Reid has found that, both in Sussex and in Dorset, it invariably contains a large percentage of rounded quartz-grains. Mr. Osborne White tells me that he has washed many samples of the material from the neighbourhood of Reading and Wargrave, and has always found a residue consisting largely of quartz-sand. He has kindly sent me a sample of the Clay-with-Flints, overlying the Chalk in a quarry at Middle Culham, near Remenham (Berkshire);

[1] Expl. of Sheet 298, Mem. Geol. Surv. 1903, p. 64.
[2] 'Geology of the Country around Dorchester' Mem. Geol. Surv. 1899, p. 37.

and a portion of this I have washed and examined under the microscope, with the following result:—

The greater part of the residue consists of rounded grains of clear white quartz, some of them stained yellowish by oxide of iron, the grains varying in size from very small to rather large. There are also many black and dark-brown grains, which seem to be rolled particles of ironstone or small concretions of oxide of iron. Both these ingredients have evidently been derived from Reading Beds. A few fragments of *Inoceramus*-shell, with a few broken sponge-spicules and arenaceous foraminifera, seem to be contributions from the Chalk. Small angular chips of flint are common in the residue, but not in the finer portion mounted for microscopic examination.

A sample from near Risborough, sent by the Rev. E. C. Spicer, F.G.S., yielded a very similar residue, the only noticeable difference being that there was a larger quantity of very fine quartz-sand, large grains being rare.

The residue of a sample from Chaul End, near Luton, sent to me by Mr. J. Saunders, also consisted mainly of very fine red sand, which the microscope showed to be grains, presumably of quartz, coated with red clay. In all cases it was difficult to free the mineral grains from the fine sticky clay which adhered to them.

III. Thickness of the Clay-with-Flints.

For the purpose of this enquiry, it is also necessary to form some idea of the average thickness or mass of the Clay-with-Flints; but this is not easy, because the clay seldom occurs as an evenly-spread deposit. On the contrary, it usually rests on an extremely-irregular surface of chalk, having sunk into hollows, funnels, and pipes which have clearly been formed by the unequal solution of the chalk. The bottoms of the hollows and depressions are often 6 or 8 feet below the summits of the intervening pinnacles of chalk, while in some places large basins occur, lined by Clay-with-Flints and filled with masses of brickearth and gravel, from 40 to 50 feet in depth; elsewhere, narrower funnels and pipes filled with the same materials penetrate the Chalk for 30 or 40 feet.

But although, in many places, it cannot be said that the Clay-with-Flints has any average thickness, there are limits within which it varies; and there are some localities where its base is not too uneven to prevent a rough estimate of its average thickness from being made by eye. In other words, one can form some idea of what its average thickness would be if it were spread out on an even base.

In the first place, I will quote some recorded observations and estimates of thickness:—

'At Oakridge, west of Wycombe Abbey [Bucks], there is a thickness of between 4 and 5 feet of stiff reddish Clay-with-Flints, in places sandy and pebbly.'[1] (H. B. W.)

'In a new road-cutting west of Hemel Hempstead Clay-with-Flints was seen, with a depth of up to 8 feet, resting irregularly on soft chalk with many flints.'[2]

'Round St. Albans this irregular deposit varies from a few inches to 4 or 5 feet in thickness.'[3]

[1] W. Whitaker, 'Geology of London' Mem. Geol. Surv. vol. i (1889) p. 286.

[2] A. G. Cameron, in *op. cit.* p. 287.

[3] H. B. Woodward, *ibid. loc. cit.*

In the country round Luton its thickness is said to vary from 2 to 8 feet. The following is unpublished information.

Near Weston, north-east of Hitchin, I saw a fairly-even spread of dark reddish-brown Clay-with-Flints, from $1\frac{1}{2}$ to 3 feet in depth, underlying loamy brickearth.

Mr. C. J. Gilbert, F.G.S., informs me that, on the high ground near Berkhampsted, there is much Clay-with-Flints, and that it is often from 10 to 20 feet thick when not associated with brickearth; but that in many places brickearths, obviously derived from the Reading Beds, lie in large potholes or solution-hollows which are lined by a bed of clay and angular flints; in such cases, the bed is thin, and is sometimes only represented by a layer of black-coated flints.

I am informed by the Rev. E. C. Spicer, F.G.S., that several of the cuttings on the Great Central Railway between Wendover and Missenden show good sections of Clay-with-Flints, that its depth varies from 1 to 6 or 7 feet, and that the average thickness might be taken at about 3 feet. At the claypits near Walter's Ash, recently described by Mr. Spicer,[1] the Clay-with-Flints forms a lining to the large basins, which are filled with brickearth, gravel, and sarsen-stones.

Mr. Spicer informs me that, in other parts of the same district, where the Clay-with-Flints forms a surface-deposit, its thickness varies from 2 to 10 or 12 feet. In order to obtain some more accurate idea of the average thickness at certain spots, he has been kind enough to measure two sections for me. The first is near Loosely Row, south of Risborough, where a cutting shows a wide depression in the Chalk filled with the usual clay-deposit; the length of the depression is 25 yards, and its depth below the soil in the centre is 10 feet, from which it lessens gradually on each side to about 2 feet; its average depth here, therefore, is 6 feet in a length of 75 feet.

The other locality is Denner Hill, south of Great Hampden, where a slope is mantled by Clay-with-Flints, and, for a length of 440 yards with a breadth of 200 yards, the depth of the clay is from 10 to 12 feet. This is an exceptional depth to be continuous over so large an area, and especially on sloping ground.

I have not been able to obtain any information as to the limits within which the thickness of Clay-with-Flints varies over Hampshire, for no observer seems to have paid much attention to it in that county, except to the north of Chichester (Sheet 317), where it has been mapped by Mr. C. Reid. No actual measurements of it are given in the Explanation of that sheet, but Mr. Reid observes that 'the total thickness seldom reaches 10 feet' (*op. cit.* p. 38).

From the particulars now given it is clear that any theory of the formation of Clay-with-Flints must be equal to accounting for its accumulation to a thickness of 3 or 4 feet over large areas.

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 39.

IV. Products of the Solution of Chalk.

From the known purity of the Upper Chalk, it will readily be granted that, if the Clay-with-Flints has been mainly derived from the dissolution *in situ* of Chalk-with-Flints, a very great thickness of this chalk must have been dissolved in order to furnish the material of the clay.

It is well known that the soft limestones of the Upper Chalk contain a very small proportion of insoluble matter; but, until recently, very few accurate analyses of these chalks existed, and even now hardly sufficient exist to furnish data for estimating the average amount of clay to be found in each zone of the Upper Chalk. Moreover, the determinations of the amounts of insoluble residue which have been made by Dr. W. F. Hume, F.G.S., and Mr. W. Hill, F.G.S., show that in some zones these amounts vary in different parts of the country. This seems to be more especially the case with the lower zones, namely, those of *Micraster cor-testudinarium* and *M. cor-anguinum*.

I have, therefore, thought it desirable to depend, as far as possible, on analyses of samples obtained from places within the area of which this paper treats. In order to increase the number of such analyses, my friend Mr. W. Hill has kindly ascertained the amount of insoluble residue in several fresh samples of chalk from the zone of *Micraster cor-anguinum*, and in one from that of *M. cor-testudinarium*. For two of these samples I am indebted to Mr. H. J. Osborne White, F.G.S.; another, from the zone of *M. cor-anguinum* at Winnal near Winchester, was sent by Mr. Charles Griffith, F.G.S.; and the fourth was obtained by Mr. W. Hill himself at Knebworth, south of Stevenage in Hertfordshire.[1]

Combining the results of these analyses with a selection from those previously made and recorded,[2] we get the following averages for four of the zones:—

(1) Residues in the Zone of *Micraster cor-testudinarium.*

	Grammes.
Chalk from Stourpaine (Dorset)	2·48
,, ,, Lewes (Sussex)	0·66
,, ,, Dover (Kent)	0·61
,, ,, Remenham (Berks)	1·43
,, ,, Medmenham (Bucks)	3·72
,, ,, Hitchin (Herts)	0·88
	6)9·78 = average of 1·63.

[1] It should be mentioned that the analysis of a sample referred to Hitchin in vol. iii of the Geological Survey-Memoir on the Cretaceous Rocks of Britain (p. 320) was really of chalk obtained at Knebworth.

[2] See 'The Cretaceous Rocks of Britain' Mem. Geol. Surv. vol. iii (1904) pp. 309 *et seqq.*

(2) RESIDUES IN THE ZONE OF *MICRASTER COR-ANGUINUM.*

	Grammes.
Chalk from Blandford (Dorset)	1·19
,, ,, Durnford (Wilts)	2·00
,, ,, Winnal (Hants)	0·81
,, ,, Crondall (Hants)	1·46
,, ,, Culham (Berks)	1·38
,, ,, Knebworth (Herts)	2·15
,, ,, Dover (Kent)	1·20
	7)10·19 = average of 1·45.

(3) RESIDUES IN THE ZONE OF *MARSUPITES.*

	Grammes.
Chalk from Blandford (Dorset)	1·10
,, ,, Arundel (Sussex)	1·24
,, ,, Margate (Kent)	0·99
,, ,, Salisbury (Wilts)	0·95
,, ,, Crondall (Hants)	0·87
	5)5·15 = average of 1·03.

(4) RESIDUES IN THE ZONE OF *ACTINOCAMAX QUADRATUS.*

	Grammes.
Chalk from Whaddon (Wilts)	0·687
,, ,, Milford (Wilts)	0·607
,, ,, Culver (Isle of Wight)	0·753
,, ,, Otterbourne (Hants)[1]	0·880
	4)2·927 = average of 0·73.

From the foregoing analyses it appears that there is a gradual diminution in the amount of insoluble residue as we ascend in the Upper Chalk, from the zone of *Micraster cor-testudinarium* to that of *Actinocamax quadratus.* If we take the two lower zones together, as constituting that part of the Chalk in which flints are most numerous, we find that equal quantities of them will yield an average percentage of 1·54 of insoluble residue. The solution of equal quantities of the two middle zones will yield 1·24 per cent., and equal quantities of the two higher zones will yield only 0·88 per cent. of insoluble residue.

This, however, is percentage by weight; and if we wish to calculate how many cubic inches of residue will be left by the solution of a given mass of chalk, we must allow for the difference in the weights of chalk and clay. Here, again, it has been necessary to make special experiments and estimations for the purpose of this paper, because the required information did not exist. Thus I could not find that anyone had determined the comparative weights of different kinds of chalk, I could find no record of the weight

[1] This is taken from an analysis made by M. Duvillier, and published by Prof. Barrois in his 'Recherches sur le Terrain crétacé supérieur de l'Angleterre & de l'Irlande' 1876, p. 42.

of Clay-with-Flints, and I felt equally sure that different kinds of clay differ also in weight.

In Sir C. W. Pasley's book on 'Limes & Cements'[1] it is stated that 'one cubic foot of solid chalk, such as is obtained near Chatham, weighs when perfectly dry about 90 lbs.'; but in a table on p. 142 he gives the weight of a cubic foot of pure dry chalk as 94·99 lbs., which is practically 95 lbs. The chalk to which Pasley refers was probably obtained from the zone of *Micraster cor-testudinarium*. Desiring, however, to have confirmation or correction of this, I asked Mr. W. Hill to ascertain the actual weight of small cubes cut from the samples of chalk sent to him. This he did, dissolving the cubes afterwards, with the results already recorded. Pieces were cut and trimmed as accurately as possible to form 1-inch cubes; they were dried for 5 or 6 hours at 120° C., and then weighed, with the following results:—

				Grammes.
Cube of Remenham chalk weighs			....	26·05
„	Knebworth	„	„	25·28
„	Culham	„	„	32·19
„	Winnal	„	„	30·25
				4)113·77 = average 28·44.

These results show that there is considerable variation in the weight of pure white Upper Chalk, even in the same zone of *Micraster cor-anguinum*, to which the last three belong. Let us first consider the Remenham chalk, for Sir C. W. Pasley's Chatham chalk probably came from the same zone. The weight of one gramme is ·002 of a pound, consequently 1 cubic inch of Remenham chalk weighs ·0521 of a pound. Multiplying this by 1728, we find that a cubic foot of the same chalk will weigh slightly over 90 lbs., which is the weight given for Chatham chalk—a curious coincidence.

The mean weight of all four samples is 28·44, and this, multiplied by ·002, gives ·05688 of a pound; and again, multiplying by 1728, we get the result that a cubic foot of the average kind to be found in these two zones weighs 98·288 lbs. This is rather more than the greater weight given by Pasley, but we shall not be far wrong if we take the weight of a cubic foot of such chalk as 98 lbs.

The determination of the weight of a cubic inch of Clay-with-Flints proved to be much more difficult. The plan adopted was to square roughly with a knife and then dry the cube, finally to dress it accurately with a file, and test it with calipers. Some samples, collected in dry weather, broke up so much that only half-inch cubes were obtainable; others, although moist, were sandy and friable for that reason. Out of many samples tried, Mr. Hill has only been able to make five satisfactory cubes, and three of these were half-inch cubes. From a sample obtained from the top of a quarry at Knebworth he cut two half-inch cubes, the mean weight of which was

[1] 2nd ed. (1847) pt. i, p. 4, 8vo. London.

4·33 grammes; this is equivalent to 34·64 grammes per cubic inch. Another half-inch cube, from the clay in a pipe at the same place, weighed 4·5 grammes, equivalent to 36 per cubic inch. From two samples obtained by Mr. J. Saunders near Luton, two good cubic inch-blocks were cut, one weighing 33 and the other 33·53 grammes.

From these figures we deduce a mean value which cannot be far wrong, thus one cubic inch of

		Grammes.
Knebworth clay...............	weighs	34·64
Do. do. (pipe)	,,	36·00
Luton (No. 1) clay	,,	33·00
Do. (No. 2) do.	,,	33·53
		4)137·17 = average 34·04.

An average cubic inch of Clay-with-Flints from these places weighs 34 grammes, which is ·068 of a pound: consequently, a cubic foot of clay weighs $1728 \times {\cdot}068 = 117{\cdot}5$ lbs.

Thus, if the Clay-with-Flints has been derived from the Chalk, its weight as compared with that of Upper Chalk is as 117·5 to 98. Further, around the London Basin the clay must have been chiefly obtained from the solution of the zones of *Marsupites* and *Micraster cor-anguinum*, for it is on one or the other of these that the Reading Beds generally rest. If, therefore, we suppose that 100 cubic feet of chalk be dissolved, half consisting of one zone and half of the other, and assuming the percentage of insoluble residue to be 1·24 by weight, the mass of the residue will be $117{\cdot}5 : 98 :: 1{\cdot}24 : x$. This works out as 1·03; consequently, the solution of a column of 200 vertical cubic feet of these two zones will yield 2·06 cubic feet of clay. In other words, in order to produce a layer of clay 2 feet thick, a thickness of 200 feet of such chalk will have to be dissolved, and the solution of 100 feet will produce only a 1-foot layer. If composed entirely of chalk of the *Micraster cor-anguinum*-zone, the layer produced by the solution of 100 feet will be 1·2 feet thick.

In the area between the London and Hampshire Basins, it is mainly the chalk of the zones of *Actinocamax quadratus* and *Marsupites* which would have suffered, and these only yield a combined percentage of ·88 by weight; the percentage by mass will be only ·73. Consequently 100 cubic feet from these zones will produce a layer of clay only 9 inches thick, and it would take 200 feet of them to produce a layer of 18 inches over the whole area, supposing it to be all retained on the area and none of it lost by water-transport during the process of solution. It is very unlikely, however, that it could be so retained on the plateaux without any waste, and much more probable that half of it would be carried down into the valleys.

In any case, it is clear that, if Clay-with-Flints consists half of clay and half of flints, the possibility of the derivation of the clay-portion from the Chalk must depend entirely upon the thickness of Chalk which can be proved to have been destroyed in any given district.

There is, however, another way of testing the probability of such derivation, and this is to estimate the proportion of flints to clay that would result from the solution of any given thickness of chalk, for in the foregoing calculations the flints have been omitted.

In the zone of *Micraster cor-anguinum* layers of flints are very frequent, and scattered flints sometimes occur in the chalk between them. In Kent and Sussex measured sections have shown that layers of flints frequently occur every 3 feet, and that sometimes they are only 2 feet apart; records of borings also often mention flints at intervals of 2 or 3 feet, but in the higher part of the zone they are not quite so frequent. We shall probably be underestimating the quantity of flints, if we assume that their average distance apart in the whole zone is $3\frac{1}{2}$ feet; and if we also assume that the average thickness of the flints is 3 inches, then every 14 feet of chalk will contain a depth of 1 foot of flint-nodules, and 98 feet of this chalk will yield 7 feet of flints.

In round numbers, therefore, the solution of 100 feet of *Micraster cor-anguinum*-chalk will produce a layer of flints 7 feet thick, together with enough clay to form a layer about 14 inches deep. Hence there would be about six times as much flint as clay in the mixture, and the product would not be 'clay-with-flints,' but a bed of flints with about just enough clay to fill up the interstices between the nodules.

In the zones of *Marsupites* and *Actinocamax quadratus* the flints are much less numerous. They do occur, however, in the latter zone at distances of from 6 to 9 feet apart, and round the London Basin flints are found in the *Marsupites*-zone, though sparsely. We may perhaps estimate them as occurring in these zones at 8 feet apart, but in quantity only enough to form a continuous layer 2 inches thick. At this rate there will be only twelve layers in 100 feet, with a total thickness of 2 feet of flints. The same thickness of chalk, if composed of equal parts of the same zones, will yield 9 inches of clay; and in this we should have something more like Clay-with-Flints, but still containing nearly three times as much flints as clay; whereas, in the real material, the proportion is only 1 to 1.

If we combine 100 feet of *Marsupites*-chalk and 100 feet of the *Micraster cor-anguinum*-zone, the 200 feet will yield a layer of flints 9 feet deep and one of clay about 2 feet deep. The mixture would be a clayey gravel, the proportion of clay to flints being nearly as 1 to $4\frac{1}{2}$.

V. Inferences to be drawn from the Distribution of the Clay-with-Flints.

From the conclusions arrived at in the preceding pages, it is clear that the stratigraphical relations of the tracts of Clay-with-Flints, both to the Chalk and to the Eocene Series, must be carefully considered. In this connection, it is necessary to remember that the Chalk had been raised and flexured to some extent before the

deposition of the Eocene beds upon it; so that, when viewed as a whole, the Eocene strata are entirely unconformable to those of the Chalk. Thus the local base of the Eocene Series rests in different districts on different portions of the Upper Chalk, from the zone of *Belemnitella mucronata* to that of *Micraster cor-anguinum*, and it is very probable that (in some places) it rested on the zone of *Micraster cor-testudinarium*, if not on that of *Holaster planus*. In other words, the surface which received the Eocene deposits was a surface which had been planed across a raised and broadly-curved or flexured mass of Chalk.

Further, in one part of the region, namely in Surrey and Kent, elevation and erosion seem to have been renewed in early Eocene time, for Mr. Whitaker has shown [1] that the Oldhaven and Blackheath Beds overstep both the Woolwich and Thanet Beds, so as to rest upon the Chalk. This may have taken place over a large area in the northern part of the Weald, when the Chalk extended much farther south than it does now.

Lastly, it is well known that both Chalk and Eocene were subjected to still greater disturbance in Miocene and Pliocene times, along lines that were more or less parallel to the great post-Oligocene flexure of the Isle of Wight. I think it almost certain that the flexuring which took place before Eocene times was of slight intensity; and that only a broad and low geanticline was then produced, the curvature of which included, not only the space between the London and Hampshire Basins, but also part of the London Basin itself: the more pronounced flexures which occur within this geanticline being wholly or mainly of post-Oligocene date.

These later flexures have a peculiar arrangement, occurring as discontinuous periclines, that is, as local elliptical domes and basins which are not always arranged along axial lines, but often alternate *en échelon*, the termination of one periclinal convexity passing below the beginning of a cymboid basin, or trough, which is flanked on each side by elongate convex periclines, all of them dying out again within a certain distance. Such an arrangement of flexures is found, for instance, in the country between Winchester and Salisbury. The Kingsclere tract is another notable instance of a convex pericline.

Now, if the Clay-with-Flints has no special relation to the Lower Eocene beds, but is a residue from the Chalk, the largest tracts of this argillaceous residue should occur over the domes and convexities which have been exposed to the greatest amount of quiet subaërial detrition since Eocene time; and the smallest and thinnest should lie in the synclines from which less chalk has been removed. On the other hand, if the Clay-with-Flints is mainly composed of residue from the basal Eocenes let down into the Chalk, it will naturally be in greatest force over those tracts from which the least amount of chalk has been removed, and on which traces or outliers of the Eocene deposits still remain; while it will be entirely absent from

[1] Quart. Journ. Geol. Soc. vol. xxii (1866) p. 420; and Mem. Geol. Surv. vol. iv (1872) p. 240.

the domes and anticlines. In this way, therefore, the distribution of the clay-tracts should clearly indicate the source from which the Clay-with-Flints has been chiefly derived.

There is, however, one large area in which the relations of the Clay-with-Flints are complicated by several special circumstances, and the consideration of which I shall leave to others who have better acquaintance with it. This area is that of Kent and Eastern Surrey, where the Thanet Beds are the lowest member of the Eocene Series, and where also the Oldhaven Beds seem to have passed over them southwards onto the Chalk. This area also was submerged in Lower Pliocene times, and there seems to be some uncertainty about the relation of the Lenham Beds to the Clay-with-Flints. Mr. Reid states that, on Lenham Down,[1] patches of Lenham Beds underlie extensive sheets of Clay-with-Flints; on the other hand, Prestwich had long ago figured and described a layer of brown and black clay with flints, as underlying the Lenham Sands and resting on the Chalk, not far from the same place. Its position according to Prestwich seems natural; but its position according to Mr. Reid seems difficult to understand.

I shall, therefore, confine myself in the following pages to a consideration of those areas where the Reading Beds form the lowest member of the Eocene Series, and where no marine Pliocene Beds occur as a disturbing factor.

Let us turn first to the country which lies west and north-west of the London Tertiary Basin. Anyone who will study the published Drift-editions of the 1-inch maps of the Geological Survey, such as Sheets 267, 268, etc., will see that there appears to be a very close connection between the Reading Beds and the areas mapped as Clay-with-Flints. It must, of course, be remembered that the latter include the overlying loam and brickearth where such materials occur; but these are admitted to be inseparable from Clay-with-Flints.

The noticeable point is, that these loams, with their basal layer or fringe of Clay-with-Flints, behave as if they were merely disintegrated portions and outliers of the Reading Beds.

In the far west of the London Basin, that is, in the western parts of Wiltshire and Berkshire, the tracts of Clay-with-Flints occur on ridges and plateaux which are clearly portions of an inclined plane rising towards the outer escarpment of the Upper Chalk. The material seldom descends far down the slopes of these ridges, except in places where there is reason to believe that landslips have occurred; as a rule, the average level of the boundary-lines is little below that at which outliers of Eocene occur or might occur. In other words, the surface on which the tracts of Clay-with-Flints lie is practically a prolongation of the basal Eocene plane. Moreover, the tracts do not become larger and thicker in the direction of the Chalk-escarpment, as should be

[1] 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, p. 45.

the case if both clay and flints have been derived from the solution of the Chalk; on the contrary, they become smaller and thinner, with a surface-soil that is more crowded with flints, as we should expect if these outer tracts had been exposed to detrition for a longer time than those nearer to the main mass of the Reading Beds.

It will also be noticed that the positions thus occupied by the tracts of Clay-with-Flints quite preclude the idea that any great thickness of Chalk can have been dissolved from beneath them since the removal of the Reading Beds. It is true that, on the Marlborough Downs, and to the north and north-west of Lambourn, the Clay-with-Flints rests upon a lower zone of the Chalk than does the main mass of the Eocene; but there is good reason to believe that the Eocene passed transgressively over the surface of the Chalk towards the west, so that the Reading Beds stepped from higher to lower parts of the Chalk as they spread westwards to and beyond the present escarpment-ridge.

North of the Thames Valley the Clay-with-Flints behaves in just the same way, rising along the Chalk-ridges with the Eocene outliers, up to the summit-ridge of the Chiltern Hills. Farther north, round Luton, it is associated with thick masses of brickearth which seem to pass into loam and brickearth of Glacial age.

I believe that much of the so-called 'Middle Glacial' loam in the counties of Bedford, Hertford, and Essex has been reconstructed from the brickearths, which were themselves derived from Reading Beds; thus, near Weston, north-east of Hitchin, I have seen Clay-with-Flints beneath loam, in a position which gave strong ground for thinking that both passed under the neighbouring Boulder-Clay.

Clay-with-Flints often wholly or partly surrounds outliers of Reading Beds, or connects two such outliers, without descending far below the level at which the local base of the Reading Beds is found. In fact, if the loam and brickearth have been formed from the disintegration of the Reading Beds, as is generally supposed: then it seems impossible to avoid the conclusion that the formation of the Clay-with-Flints was concomitant with that of the brickearths, and also with the detrition and diminution of the Eocene outliers.

Moreover, although but one colour is assigned to such tracts on the Geological Survey-maps, yet the index on the margin always states that this colour includes 'Clay-with-Flints and brickearth' (or loam). Now, the brickearth, which is thus associated with the Clay-with-Flints, is sometimes underlain by that material, but sometimes rests directly upon the Chalk; further, this brickearth often includes beds or masses of quartz-sand. Hence, it is clear that a theory designed to explain the formation of Clay-with-Flints alone will not suffice; it must be one that will account for the disintegration, disturbance, and subsidence of masses of Eocene clays and sands *pari passu* with the formation of the Clay-with-Flints.

It must be recognized, in fact, that Clay-with-Flints is not a distinct and definite material, like Boulder-Clay, which can be separately mapped and receive an index-colour for itself: it is inseparably associated with a more or less confused assemblage of

brickearths, loams, sands, and gravels. Small patches can doubtless be found which consist entirely of Clay-with-Flints; but larger tracts almost always include masses of mottled clay, sand, and gravel, and sometimes accumulations of sarsen-stones, or of unworn flints.

One good instance of such associated materials has already been cited (p. 138), and another may be quoted from a recent memoir, as occurring in the Aldworth and Yattendon area above mentioned.[1] At Buttonshaw Kiln, south-west of Aldworth, Mr. Bennett saw a section showing

'6 feet of large unworn flints and sarsens resting irregularly on rusty-brown and black-stained clay. A hole dug for clay near the kiln showed a mixture of plastic clay and coarse red sand, capped with Clay-with-Flints. The plastic clay seemed in process of conversion into the rusty-brown clay.'

Let us take an actual example of the relative positions which the Eocene and the Clay-with-Flints frequently occupy. For this purpose I choose the large outlier of these combined deposits round Yattendon and Ashampstead, west of Reading. This tract is completely isolated by the valleys of the Pang and the Thames; it includes no fewer than seven outliers of Reading Beds, connected and more or less surrounded by Clay-with-Flints. At the extreme north-western end (north of Aldworth) the ground rises to a height of 600 feet, and there is a very small patch of Reading Beds accompanied by Clay-with-Flints at the same level.

South-west of Aldworth is a larger outlier of Reading Beds, the base of which descends to about 520 feet, while that of the Clay-with-Flints near the same point is some 20 feet lower. On the south there is a continuous tract of Clay-with-Flints, the base of which falls rather rapidly to a level of about 320 feet near Yattendon; but this evidently accords with the original slope of the Eocene basal plane, for a large outlier of Reading Beds sets in at Yattendon, its base sloping south-westward from about 350 feet to a little below the contour of 300 feet. At the same time, the Clay-with-Flints thins out rapidly against the Eocene boundary.

The other Eocene outliers lie on a similar sloping surface of Chalk, and the base of the connecting tracts of Clay-with-Flints slopes in the same direction, that is, south-westward; but its border passes below the level at which any Eocene is exposed, until it reaches the contour of 300 feet.

Again, there are cases where a kind of Clay-with-Flints seems to overlap onto the border of an Eocene tract. On this point, Mr. Osborne White informs me that he believes such overlap to be of frequent occurrence, although it is not easy to prove the fact, because it is very seldom that a continuous section from the surface of Chalk to the surface of Eocene is actually exposed. At Cadmore-End Common (Oxfordshire) he has seen a section 10 feet deep, showing Reading Beds (mottled loam) overlain by brown loam full of white angular flints, both being covered by a loamy soil full

[1] 'Geology of the Country around Reading' Mem. Geol. Surv. 1903, p. 60.

of pebbles. There are several exposures of similar clay on the outlier of Reading Beds at Maiden Grove (Oxon). I have the same authority for stating that most of the Reading-Bed outliers, which occur among the Clay-with-Flints of the Berkshire Downs, are overlapped at their edges by clay and loam with angular flints. The flints in such clays are almost always white and angular unbroken flint-nodules being rare; but he believes the material to be continuous with the surrounding Clay-with-Flints.

Mr. White has also noticed that this transgression of the Clay-with-Flints onto Eocene tracts occurs most frequently on the sides which face up the slope of the Chalk-surface, and much less often on the lower or dipward side of the outliers; a fact which suggests a certain amount of slow movement from the main watershed.

The intimate relation between the occurrence of Clay-with-Flints and the basal plane of the Eocene Series is brought out still more strongly by a study of the area which lies between the London and Hampshire Basins. There is a further advantage in dealing with this area, in the fact that the geological mapping of it has been completed, and published on the new series of 1-inch maps (Sheets 282, 283, 284, 298, 299, & 300), so that these can be referred to in confirmation of the statements made below.

In considering this area, we must remember what has been said on p. 144, that the structure is complex, and that the flexuring was not all produced at one period; that the main broad geanticline is of pre-Eocene date, and was planed down before the Reading Beds were deposited, both Chalk and Eocene being subsequently bent into smaller and narrower folds.

Beginning with the western part of the area (Sheets 282 & 298), we find that these include a surprisingly-small amount of Clay-with-Flints. In the far west, and just outside the limits of Sheet 282, there is a tract of some length on the highest ridge of the downs which lie between Imber and Warminster. On the north, there is a curvilinear tract on the summit of the downs south of Chirton and Wilsford (600 to 700 feet), the boundary of the flinty clay being in some places not more than 20 feet above the outcrop of the Chalk-Rock. Farther east, near Upavon, there are three small patches below 600 feet; but none has been mapped on Pewsey or Milton Hills, although the latter rises to 782 feet above O.D. The only other place within the area of Sheet 282 where Clay-with-Flints has been mapped is on Sidbury Hill, where it flanks a small outlier of Reading Beds at an elevation of about 700 feet.

The southern portion of the area included in Sheet 282 and the northern part of that which comes into Sheet 298 form together the central portion of Salisbury Plain. All of this area lies below 600 feet, and is traversed by a network of branching-valleys. The surface of what was originally a plain or plateau has evidently been graded and lowered by long exposure to the action of rain, and the ridges are capped by a variable thickness of flint-débris, consisting partly of entire and unworn flints, and partly of broken angular

fragments, but nothing was found that could be mapped as Clay-with-Flints, except a few patches near Wilsford and Woodford. Now, if this material is mainly a Chalk-residue, how can its absence on this part of Salisbury Plain be explained? If, on the other hand, it is mainly an Eocene residue, we should not expect to find it far below the level of the basal Eocene plane.

Within the area of Sheet 298, besides the few small patches above mentioned, a long tract of Clay-with-Flints caps the ridge which lies between the valleys of the Wily and the Nadder, pointing eastward to another patch on the slope of the hill north-west of Salisbury; and there are other spreads of varying extent in the southern part of the district.

The relations of these tracts of Clay-with-Flints to the tectonic structure of the country are interesting and suggestive. The ridge between the Wily and the Nadder is capped by red and brown Clay-with-Flints for a length of 9 miles, and it lies over the central axis of a syncline which intervenes between the anticlines of the Vales of Wardour and Warminster. It is, therefore, probable that the base of the Eocene lay not very far above the summit of this ridge, and that very little chalk has been removed from the watershed in post-Eocene times, either by solution or by any other process. The presence of the Clay-with-Flints here is quite comprehensible if it is mainly an Eocene residue, but is inexplicable on the Chalk-residue hypothesis.

It may be mentioned that the western end of this tract of Clay-with-Flints rises to a level of 700 feet, and that Claypit Hill on the other side of the Wily valley, north-east of Codford, is capped by a patch of materials (mottled clay and sand) which, although disturbed, are recognizable as remnants of Reading Beds.[1] This outlier probably owes its preservation to its having been let down into a hollow in the Chalk, or to an ancient landslip. Its present summit is only 586 feet above Ordnance-datum, but it suffices to show that Reading Beds lay over this area at some level between 600 and 650 feet.

The materials derived from the Reading Beds are here overlain by a peculiar deposit, consisting of yellow sandy clay full of angular flints and small quartz-pebbles, which is described by Prestwich as extending along the ridge of Codford Hill, but is not shown on the Geological Survey-map. Such a deposit seems to resemble the Plateau-Gravel of Berkshire more than the Clay-with-Flints, although it may be a contemporary variation of the latter.

How the flexures above mentioned are continued eastward is not certain, except as regards that of the Vale of Wardour, which is cut off obliquely by a fault striking roughly from west-north-west to east-south-east. The intermediate syncline seems to be deflected southward, so as to pass below Wilton and Salisbury, and may possibly be continued into the syncline of the Eocene tract at Alderbury. The Wily anticline appears to be prolonged to Lower

[1] See Prestwich, Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 144, and Geol. Mag. 1898, p. 412.

Woodford on the Avon, but here it seems to die out; and I am inclined to regard the small scattered tracts of Clay-with-Flints around Woodford as being disposed round the periclinal termination of this anticline, a position which would account for the low levels at which they occur (400 to 300 feet).

On the east side of the Avon Valley another set of flexures come in, which seem to be independent of those on the west. Here we find a synclinal trough filled with Eocene, stretching eastward from Alderbury. This is bounded on the south by a well-marked anticline of bare chalk, and on the north by what is probably a monoclinal rise, carrying the basal plane of the Eocene Series up to a level which is much higher than the present general level of Salisbury Plain. Here it is interesting and instructive to observe several tracts of Clay-with-Flints, which behave exactly as if they were outliers of Reading Beds, their southern boundaries being at about 300 feet, while on the north they reach a height of about 440 feet. On a line with them, but at a slightly-higher level (486 feet), near Laverstock is a small outlier of Reading Beds; and to the north of them, on Thorny Down, is another outlier at 533 feet. This last is about 300 feet higher than the outcrop of the Reading Beds in Clarendon Park, only 3 miles to the south, and shows the rapid rise of the basal plane or floor, upon which the Eocene rests.

These small outliers, and the others previously noted as occurring farther north in the area of Sheet 282, enable us to construct a section showing the relative level at which the Eocene floor passed over this part of Salisbury Plain (see Pl. VI, fig. 1). It also indicates the manner in which the higher zones of the Chalk were planed off prior to the formation of the Reading Beds, and thus demonstrates the compound nature of the geanticline between the London and Hampshire Basins.

Passing now to the area included within Sheet 283 of the Geological Survey-map, a casual view might convey the impression that the tracts of Clay-with-Flints were distributed in an irregular manner without respect to present levels, and without any special relation to the flexuring of the district; but a closer examination shows that there is a definite relation between them and the post-Eocene flexures.

Broadly speaking, the structure of the area is as follows. Its northern part is traversed by an anticline, or rather by a series of periclinal domes, which are made apparent by the outcrops of Selbornian and Cenomanian strata near Grafton, Shalbourn, Woodhay, and Burghclere. From this irregular anticline the beds of the Chalk slope southwards into a deep periclinal basin, the centre of which must lie near the town of Andover, for near this place the zone of *Marsupites* is found at levels of from 300 to 400 feet.

If this basin be the complement of the northern anticline, and was formed in post-Eocene times by a movement which carried the basal plane of the Eocene with it, and, further, if the Clay-with-Flints be mainly an Eocene residue: then we should expect to find

the tracts of Clay-with-Flints continually descending to lower levels as they are followed southwards. This is the case: in the northern part of the area the Clay-with-Flints is only found on the summit of ridges that rise to 700 or 800 feet, but in passing southwards, and especially from north-west to south-east, we find it descending gradually to about 300 feet. Thus, on Tidcombe Down in the north-west the Clay-with-Flints sets in at a height of about 830 feet, and there are several large tracts of it to the south-east, the boundary-lines of which gradually slope from 700 to less than 400 feet, and east of Andover it occurs on the *Marsupites*-chalk at a level of 300 feet.

In this connection it is especially interesting to find that, in all the larger tracts, Clay-with-Flints is associated with, and often covered by, thick masses of brickearth and sandy mottled clays which have evidently been derived from the destruction of the Reading Beds. Further, in Harewood Forest, east of Andover, patches of clean mottled clay and yellow sand occur, which were originally described as outliers of Reading Beds [1]; but, on the more recent map issued in 1898, they are included in the 'Clay-with-Flints and Loam.'

From the description given in the memoir above cited, it would seem that masses of little-altered Reading Beds do occur here at the low level of 300 feet: thus confirming the suggestion above made, that the Andover Chalk lies in a post-Eocene syncline, for these remnants cannot be far removed from the position that they occupied when *in situ*. It is also stated that some of the adjacent material resting upon the Chalk is a reddish-brown mottled clay containing pebbles, and having a layer of large black-coated flints at its base: the whole being overlain by a gravelly deposit, consisting of rounded and angular flints in a matrix of reddish-brown clay. We seem to have here all the materials for making the mixture usually known as 'Clay-with-Flints', and I cannot help thinking that we are here provided with an illustration of a phase in the making of Clay-with-Flints; with a case, in fact, in which further developments were arrested, owing to some local conditions which may or may not be discernible by a more complete study of the district.

Close to the northern edge of the area in Sheet 283, and near Woodhay Clumps, is a small but instructive outlier of Reading Beds which touches the contour of 900 feet, and is only about 180 feet above the neighbouring outcrop of the Chalk-Rock. Hence, though solution of the Chalk may have caused it to subside or slip considerably below its original level, its position seems to indicate that the thickness of chalk removed from this locality before the time of the Reading Beds was greater than usual. The Eocene outlier is surrounded by Clay-with-Flints, which extends along the southward prolongation of the ridge, its basal boundary passing gradually from 900 to 650 feet. Other tracts on the south-east

[1] See 'Geology of Parts of Berks & Hants' Expl. of Sheet 12, Mem. Geol. Surv. 1862, p. 28.

take it from 600 down to about 400 feet, and finally patches near Whitchurch carry it down to 300 feet.

The natural inference from these facts is that we are following a slope which coincides approximately with the inclination given to the basal plane of the Reading Beds by post-Eocene disturbances; and that, when allowance has been made for solution, downwash, and landslips, the tracts of Clay-with-Flints may be regarded as having been formed out of the remnants of so many ancient outliers of Reading Beds. This view receives a striking confirmation from the fact that at East Stratton, only 7 miles south-east of Whitchurch, an outlier of the Reading Beds actually occurs at a level of about 300 feet, and is surrounded by patches of Clay-with-Flints. I shall recur to this outlier in the sequel (p. 155), as it comes within the area of Sheet 300; but its existence testifies to the low level at which the Lower Eocene deposits originally lay over this part of Hampshire, and to the small vertical thickness of chalk which has been removed from the post-Eocene surface.

Proceeding to the area south of Andover and Whitchurch (Sheet 299), we find a wide tract over which Clay-with-Flints either is absent, or occurs only in small scattered patches. This tract coincides with the anticline of Stockbridge, which was first discovered and described by Prof. Barrois.[1] He regarded it as a continuation of the Winchester uplift; but, on this point, I venture to differ from my friend and confrère, believing it to be an independent periclinal dome which may be prolonged for some miles to the westward, but dies out rapidly to the east.[2] However this may be, it is doubtless a post-Eocene uplift, and consequently an area over which subaërial detrition has been great. If, therefore, Clay-with-Flints were a Chalk-residue, it should be in strong force; while if it be derived from the Eocene, it is easy to understand its absence, except for two small patches near Stockbridge itself.

The western part of the area in Sheet 299 adjoins that of Salisbury (Sheet 298), and the flexures noticed in the latter are continued eastward to the valley of the Test. The anticline on the south passes through Dean Hill and dies out toward Lockerley. The syncline filled with Eocene deposits which runs eastward from Alderbury also seems to disappear near Mottisfont; while the Stockbridge uplift above mentioned is probably a development of the monocline traced to the north of Clarendon.

A glance at the geological map will show that tracts of Clay-with-Flints occur in connection with these flexures, and are disposed

[1] 'Recherches sur le Terrain Crétacé de l'Angleterre & de l'Irlande' 1876, p. 52.

[2] The curvature of the Stockbridge flexure must be slight and low, for the zone of *Micraster cor-testudinarium* has only been found near Stockbridge; and Mr. C. Griffith, F.G.S., informs me that to the westward, along the valley of the Wallop, all the pits seem to be in the zone of *M. cor-anguinum*, while northward at Grately he found *Uintacrinus*-chalk, and southward still higher beds come in.

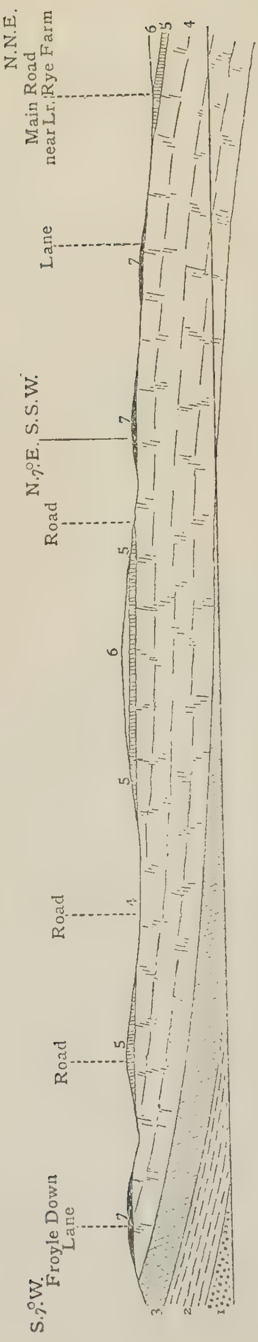
exactly in accordance with the view that they are the remnants of Eocene outliers. Thus, on Dean Hill there are four patches of Clay-with-Flints, which are so arranged that their boundaries show an eastward slope from 500 to 300 feet; and the largest one slopes south-eastward from the ridge-summit at 440 feet to about 350 feet, its termination being within half a mile of the Eocene boundary at 300 feet above Ordnance-datum. The tracts on the northern limb of the syncline are similarly disposed on a rising plane, which appears to be the natural prolongation of the basal Eocene plane. Thus, at a point near the junction of Sheets 298 & 299, the Eocene boundary-line is at a level of 222 feet; and north of this tracts of Clay-with-Flints rise from 300 to a height of 500 feet at Winterslow, in a distance of about $2\frac{1}{4}$ miles.

Farther east, near Winchester, we find another distinct uplift coming in, which does not seem to be connected with either of the anticlines to the westward. This may be called the Winchester pericline, but it is really the periclinal termination of the Petersfield and Meon-Valley anticline. The centre of this pericline does not coincide with the centre of the Lower Chalk-exposure, but with the eastern end of that exposure near Chilcombe, where the base of the Middle Chalk is 160 feet higher than it is below the alluvium of the Itchen. The strata are, in fact, dipping westward from this centre, as well as northward and southward, and the pericline must die out between the valleys of the Itchen and the Test.

This being so, it is interesting to note the complete absence of Clay-with-Flints on the Chalk-downs west of Winchester, for a distance of about 5 miles; and further, when tracts of it do set in, they are disposed on the southern, western, and northern slopes of these downs, exactly as if they were the remnants of a sheet of Eocene clays which had overlain the Chalk and had been included in the periclinal flexure. I have little doubt that they are such remnants, modified by subaërial agencies and sunken somewhat from their original position by solution of the underlying chalk. It will be noticed that, at Braishfield, there is an outlier of Reading Beds which is equidistant from the main outcrop and from a small patch of Clay-with-Flints at a higher level, leading on to the larger tract of Farley Down. This ascends to over 500 feet, and a section across the district here would appear as in Pl. VI, fig. 2.

Coming now to the country round Basingstoke (see Sheet 284), I venture to assert that the positions occupied by the various tracts of Clay-with-Flints in this area can only be satisfactorily explained on the hypothesis of their having originally formed part of a continuous sheet of material, which had been flexured together with the Chalk. If all the isolated tracts are so regarded, it will be seen that their connection across the intervening spaces would mantle the surface of the Chalk, in such a manner as to accord with the known or probable flexures, and with the position of the Eocene outliers. In short, the hypothesis which I advocate furnishes a

Section from Froyle Down to Rye Farm, near Crondall.



1 = Selbornian.
2 = Lower Chalk (200 feet).
3 = Middle Chalk (150 feet).
4 = Upper Chalk (450 feet).
5 = Reading Beds.
6 = London Clay.
7 = Clay-with-Flints.

[Scales, horizontal: 2 inches = 1 mile; vertical: 1 inch = 1000 feet.]

simple and natural explanation of the distribution of the Clay-with-Flints in this area, which would be very difficult to account for on the supposition of its being entirely or mainly a Chalk-residue. Thus, round Hannington there are patches which, if united, would lie on a curved surface that would partly wrap round the eastern termination of the Kingsclere pericline, and this surface, if prolonged, would meet the outcrop of the Reading Beds near Wolverton and Ewhurst.

From the high ground near Hannington the patches of Clay-with-Flints descend southward and south-eastward to a level of 370 feet, and some of them are traversed by the railway-cuttings near Church Oakley. From this low level remnants of what was once a continuous mantle rise gradually again to over 600 feet, on the high ground south of Basingstoke. I take it that this descent of the Clay-with-Flints coincides with a synclinal flexure of the Chalk between the Kingsclere pericline and the Bentley-Farnham uplift, which is little more than a monocline.[1]

As for the large spreads of Clay-with-Flints on the high ground around Farleigh, Ellisfield, Herriard, and Lasham, and thence eastward along the summit-

[1] See W. Topley, 'Geology of the Weald' Mem. Geol. Surv. 1875, p. 230; and A. J. Jukes-Browne, 'The Cretaceous Rocks of Britain' Mem. Geol. Surv. vol. i (1900) p. 10.

ridge of the Chalk-escarpment: these seem to occur at levels which would have been occupied by a continuation of the Eocene deposits westward from Farnham and Crondall through the two outliers of Reading Beds west of the latter place. A section drawn through these two outliers and through the patches of Clay-with-Flints north and south of them, shows that the latter occupy positions which must previously have been held by the Reading Beds (see the accompanying text-figure, p. 154).

Of the area in Sheet 300 to the south of that described above, it is unnecessary to give much detail. Its chief features in relation to my subject are as follows:—

1. The large continuous sheet of Clay-with-Flints which covers the eastern part of the Upper Chalk-plateau, from which the ground slopes eastwards to the Wealden area.
2. The existence of a small outlier of Reading Beds, partly surrounded by Clay-with-Flints, at Stratton in the north-eastern corner of the district.
3. The entire absence of Clay-with-Flints in the south-eastern corner of the district, which seems to be traversed by a flexure connecting the Winchester pericline with the Meon-and-Petersfield anticline.

The extensive tract of Clay-with-Flints on the high plateau (above 500 feet), which forms the eastern border of the Upper Chalk-area, has a length of 12 miles from south to north, and is a continuation of that mapped to the north in Sheet 284. It is of very irregular shape, owing to the branching system of valleys by which it is deeply incised, and is thus interesting as an illustration of the manner in which similar large wide-spreading tracts have been cut up into isolated patches, and the way in which such patches come to occupy different levels on a sloping surface of Chalk.

This irregular tract of Clay-with-Flints helps us to look back to a time, somewhere between the Miocene Period and the Glacial Epoch, when the greater part of the Chalk-area between the present boundaries of the London and Hampshire Basins was covered by a mantle of this material, or of the deposits from which it has been derived.

The outlier of Reading Beds on the north-west takes us a step farther, and indicates one at least of the deposits out of which the Clay-with-Flints has been formed. This outlier lies just above the contour of 300 feet, and the surrounding patches of Clay-with-Flints are at about the same level, that is, from 300 to 350 feet. The remarkable fact of its occurrence has already been commented upon, but its importance can hardly be exaggerated, because it lies about midway between the London and Hampshire Basins, and because it proves that the Eocene Beds were here carried down to a comparatively low level in the geanticline, presumably by post-Eocene re-adjustments.

As the level at which Clay-with-Flints is found rises from Stratton northward, eastward, and southward, I suspect that the Eocene outlier marks the site of a periclinal basin or 'cymboid,' which probably extends for several miles westward, through

Micheldever and Sutton Scotney, where patches of Clay-with-Flints occur at a still lower level, that is, down to 270 feet.

It is, therefore, of great importance to ascertain what zone of the Chalk underlies the Stratton outlier; for, if it were found to rest on the zone of *Micraster cor-anguinum*, we should have proof of a certain amount of pre-Tertiary erosion, and should infer the existence of a broad anticline of Chalk which was subsequently indented by a local post-Eocene syncline. Whereas, if the Chalk belongs to the zone of *Marsupites*, or to that of *Actinocamax quadratus*, there would be no proof of a pre-Tertiary anticline, and we should infer that the flexure which brings the Eocene down to this level was entirely of post-Eocene date.

Mr. Charles Griffith, F.G.S. (to whom I applied for information on this point), was kind enough to visit Stratton, but could not obtain any definite evidence. The chalk-pits which he visited were much overgrown; of one exposure he writes:—

'The appearance of the chalk and the flints suggests the zone of *Marsupites*, but I saw no plates, either of that fossil, or of *Uintacrinus*.'

Westward, by the side of the railway west of Micheldever and south of Weston Colley, is a quarry from which *Offaster pilula* has been obtained; while at Micheldever Station, 3 miles north of this, the zone of *Micraster cor-anguinum* comes in.[1] Mr. Griffith has also found *Offaster pilula* in a quarry at Sutton Scotney, and *Actinocamax granulatus* in another about 2 miles north of that village. Thus, all the available evidence points to the conclusion that Stratton lies on one of the higher zones, either that of *Marsupites* or that of *Actinocamax quadratus*, and that the second of the inferences above-mentioned is correct.

Passing now to the southern part of Sheet 300, we remark an entire absence of Clay-with-Flints over the tract between Winchester and the Meon Valley. This is what might be expected, over an area where detritive agencies must have been especially active. Although it has generally been supposed that the Winchester uplift is a continuation of the Petersfield anticline, it may be objected that there is no proof of the connection between them, and that the former may terminate eastward in the district marked Temple Valley on the Ordnance map. It may be so; but if my readers have by this time gained any of the confidence which I feel in the position of patches of Clay-with-Flints as guides to the previous disposition of Eocene deposits, they will notice as a significant fact that there is no fan-shaped disposition of Clay-with-Flints round the supposed end of the pericline. On the contrary, a series of patches of this material form a curved band between Avington and West Meon, this band conforming exactly to a curved line that would unite the axes of the two uplifts.

Such a series of patches are obviously explicable as the remnants of a sheet of material which had originally spread over the whole

[1] 'The Cretaceous Rocks of Britain' Mem. Geol. Surv. vol. iii (1904) p. 188.

of an anticlinal axis, while all traces of it have been swept away over the central part of the arch and from its southern limb. The reason for the persistence of such remnants on the northern side only is also obvious from an examination of the maps (Sheets 300 & 316), for it is seen that this side has a very short drainage-slope to the valley of the River Itchen, the course of which is roughly parallel to the presumed curve of the anticlinal axis. The southern slope, on the other hand, is drained by a series of separate streams which have long southerly courses, and the ground falls in this direction to a much lower level than that on the north. Hence, valley-erosion and general detrition of the surface must both have proceeded more rapidly on the southern side, with the result that all traces of the Clay-with-Flints have been swept away, until we approach the existing border of the Hampshire Basin, when we find patches of it occurring at intervals just as if they had been outliers of Reading Beds. The same is the case north of Chichester.[1]

VI. Summary and Conclusions.

In the first place, it seems clear that the mass of the Clay-with-Flints cannot have been derived from the Chalk. Chemical analyses show that the quantity of insoluble residue in a cubic foot of chalk is so small, that the residue left by dissolving a cubic mass of Chalk-with-Flints *in situ* would not be a stratum of Clay-with-Flints, but a bed of loose flints with some clay in the interstices. More precisely, if the chalk dissolved was that of the *Micraster cor-anguinum*-zone, and was 100 feet deep, the residue would form a layer about 7 feet deep, consisting of 6 parts of flint-nodules to 1 part of clay. Let such an accumulation be contrasted with the real material, in which at least half the bulk is clay.

Again, if we consider the clay alone, and regard a depth of 4 feet of Clay-with-Flints as containing only 2 feet of clay, it would require the destruction of 200 feet of chalk from the zones of *Marsupites* and *Micraster cor-anguinum* to produce a layer of this thickness, and it would be impossible to get it without a great superabundance of flints; for, although flints are fewer in the higher zones, the insoluble residue in the chalk is also less.

Lastly, it has been shown that, in areas where the Upper Chalk evidently has suffered very greatly from solution and detrition, as on Salisbury Plain, and especially over periclinal uplifts, there very little Clay-with-Flints is to be found.

On the other hand, there is strong evidence to show that most of the material composing the Clay-with-Flints in the districts examined has been derived from the Reading Beds. These beds are an obvious source for the actual clay, and all who have washed samples of it have found that it yields a residue composed of grains of quartz and of ironstone, such as could not have come from the Chalk. Of the larger ingredients, the green-coated flints, rounded flint-pebbles, quartz-pebbles, and pieces of ferruginous

[1] See C. Reid, 'Geology of Chichester' Mem. Geol. Surv. 1903, p. 38.

sandstone, in fact all the components except the unworn flints, could be, and probably were, furnished by the Reading Beds.

A study of the stratigraphical relations of the two deposits shows that the largest and most frequent tracts of Clay-with-Flints are almost always found at levels which approximate to the prolongation of the inclined surface on which the Eocene lies; and, where they are at a distance from the main outcrop of the Eocene, the positions which they occcupy are generally those where traces and remnants of Reading Beds might be expected.

Again, the larger tracts of Clay-with-Flints frequently border or support masses of brickearth and loam which have evidently been formed out of the wreck and disruption of Reading Beds. Lastly, existing outliers of Reading Beds are often flanked or bordered by Clay-with-Flints, which sometimes passes from the surface of the Chalk onto that of the Eocene; there are also cases in which several outliers of Reading Beds are united into one connected tract by a broad spread of Clay-with-Flints.

I do not, of course, deny that some of the contents of this clay have been derived from the Chalk: the larger unbroken flint-nodules must have come from this source, and in most cases this is probably a consequence of the solution of chalk *in situ*; but I maintain that the amount of clay that can have been derived from the Chalk must have been very small, because it can generally be proved that only a small thickness of chalk can actually have been destroyed since the Eocene cover was broken up and removed. Thus, wherever outliers of Reading Beds occur among tracts of Clay-with-Flints, or wherever the inclination of the surface on which the Eocene rests can easily be prolonged as a reference-datum, it is found that the base of the Clay-with-Flints is not generally far below the level which must formerly have been occupied by Reading Beds. Here and there small quantities of Clay-with-Flints may have been let down by landslips, or have subsided into pipes and hollows, but the tracts of it which cover long ridges and plateaux are seldom found to be more than 30 or 40 feet below the datum above-mentioned, whenever an estimate can be made.

It may be objected that Clay-with-Flints does not always lie only on the summits of ridges or plateaux, but sometimes occurs on one side of a ridge, or irregularly on the slopes of a ridge. This is true, but I think that in all these cases it has either slipped down from its original level, or has been let down by solution and subsidence, and that such displacements have taken place during the carving-out and widening of the valleys at the expense of the intervening ridges. This process of valley-erosion must have gone on rapidly when the rainfall was greater than it is now, especially while the Glacial Epoch was passing away. The chalk exposed along the sides of the valleys must have yielded both to chemical solution and to mechanical erosion by the water flowing off the ridges; and extensive landslips may have occurred in many places, by which a capping of Clay-with-Flints would be carried down far below its normal level.

To sum up, therefore, I conclude that the material of Clay-with-Flints has been chiefly and almost entirely derived from Eocene clay, with the addition of some flints from the Chalk; that its presence is an indication of the previous existence of Lower Eocene beds on the same site and nearly at the same relative level, and, consequently, that comparatively-little Chalk has been removed from beneath it. Finally, I think that the tracts of Clay-with-Flints have been much more extensive than they are now. These inferences, however, do not exhaust the subject; they do not answer all the questions that we can ask about it, for there remains the question of the time and manner in which this residual product was actually formed, and this is by no means an easy question to answer.

The accumulation cannot be regarded simply as the residue left by the almost complete detrition of tracts of Reading Beds which have gradually subsided into the Chalk, and have thereby absorbed unworn and unbroken flints from that formation. The phenomena are much too complicated to be accounted for in so simple a manner. No doubt it is largely a residue of Reading Beds, and it has sunk into the Chalk; but this is not all. The basement-bed of the Reading Group has been entirely broken up, the sands have been largely eliminated from the final product, and there has been an introduction of broken flints into this product. There is also sufficient evidence to prove that many of these angular flints have travelled from higher levels, and that there has been a moving and pushing of material from higher to lower levels, the various ingredients becoming mixed and kneaded together in the process.

In order to form some conception of the conditions under which this complex product has been accumulated, I think that we must go back to the time when the Lower Eocene deposits had been removed to a large extent, but when they still remained over very large tracts outside the London and Hampshire Tertiary Basins. Such were the conditions that probably prevailed during the Pliocene Period.

We know that there are some areas, such as Salisbury Plain, from which nearly all remnants of the Eocene have been removed, and on which very little Clay-with-Flints exists. In such a case only two alternatives present themselves: either very little Clay-with-Flints was ever formed, or else the greater part of it has been entirely destroyed. I am inclined to think that its absence on Salisbury Plain is a consequence of the removal of nearly all the Eocene, before the period arrived when conditions specially favoured the manufacture of Clay-with-Flints. Further, it seems to me that this period was most probably that which included what is known as the Glacial Epoch; and I use the term *included*, because this epoch must have been only the climax of a period during which the precipitation of rain and snow must have been greater over the whole of Europe than it had been before or has been since.

I think, therefore, that we need not go back farther than to

Pliocene time to find Eocene deposits still occupying the greater part of the region between the London and Hampshire Basins, and also covering most of the ground which lies between the Chalk-escarpment and the main outcrop of the Eocene along the north-west side of the London Basin. Valleys were then being cut through these Eocene deposits, and some had doubtless been carried deep enough to reach the Chalk; but the intervening plateaux were probably so much broader, and all the minor valleys so much shallower, than they are now, that the cover of Eocene was nearly continuous.

Let us next imagine the climatic changes which took place at the close of the Pliocene Period and during the early part of Pleistocene time. At first, there would be only an increased rainfall; but this would keep all the sands and clays of the Eocene deposits in a more or less saturated condition. Later on, each winter would bring heavier falls of snow, especially on the higher ground, and eventually a time would come when the high plateaux would be covered by thick snow-caps which might only melt off entirely during three or four months of the year.

How would such conditions affect a plateau consisting of saturated Lower Eocene beds? I think that a considerable amount of movement would take place under the pressure of the snow-caps down the dip-slopes and outward from the main anticlinal flexures. Much loose sand might be pressed out from between the clays, while the latter would be greatly disturbed and broken up. By the general downward movement of the soil, flints from the higher Chalk-ridges would be carried to lower levels, and being cracked by the variations of temperature to which they must have been exposed, would furnish a supply of angular flints and flint-chips which would become mixed with the reconstructed Eocene material. Lastly, in those places where the Eocene cover had been reduced to a comparatively-small thickness of Reading Beds, these beds may have been disintegrated and reconstructed down to their very base: outlying tracts being completely broken up and crushed, or spread out over a larger surface.

The foregoing hypothesis, although arrived at independently, is really but an amplification of an opinion already expressed by Mr. Clement Reid in the following terms:—

'Another thing must be taken into account in estimating the date of any particular part of the Clay-with-Flints. It is highly probable that much of the deposit was to some extent disturbed and reconstructed during the Glacial Period, when floods, caused by the melting of the snow, or by rain falling on frozen soil, combined with creep or soil-cap motion further to mix material which had already been moved.' [1]

I only differ in thinking that the deposit was mainly formed by such movement and reconstruction as took place during the Glacial Epoch.

When the Glacial episode passed away and the climatic conditions became less severe, large tracts which had previously been covered by a normal succession of Eocene deposits must have been

[1] 'The Geology of the Country around Salisbury' Mem. Geol. Surv. 1903, p. 64.

reduced to the state now presented by the masses of so-called 'brickearth.' Much of what has been mapped as Clay-with-Flints has probably been formed from the further disintegration and detrition of these brickearths, accompanied by solution of the chalk upon which they rest. Take, for instance, such a tract of Clay-with-Flints as that around Aldworth and Ashampstead (see p. 147): the existing Eocene outliers are evidently those portions of a larger mass that escaped reconstruction during the Glacial Epoch; the surrounding and intervening tract of Clay-with-Flints consists of the remains of the disintegrated portions of the same Eocene deposits, mingled with materials which have travelled from the higher ground on the north and north-west.

The enclosure of unbroken chalk-flints in the clay could only take place where the rain had easy access to the underlying Chalk. This would, at first, be chiefly round the periphery of such a tract; but afterwards it would occur at places within the area where mechanical erosion had left only a small thickness of clay-cover, or where a growth of large trees had sent their roots through the base of the Eocene into the Chalk. Thus, under the continued action of rain, both mechanical and chemical, such a tract would diminish in size and thickness, and would be intersected by rain-channels, some of which would eventually cut down to the Chalk. It seems easy to imagine a continuance of this process until the whole mass was reduced to its present state, when it consists partly of displaced masses of Eocene clay and sand, partly of residual Clay-with-Flints: the whole having sunk down irregularly into the Chalk, until parts of it are 30 or 40 feet below the inclined plane upon which the Eocene outliers rest.

While, therefore, I do not deny that some of the material which now enters into the composition of the Clay-with-Flints may be Eocene detritus collected in the Miocene or Pliocene Periods, I think that the accumulation, as we now find it, is the result of a special set of processes which were in operation during late Pliocene and early Pleistocene times. In more recent times, I think that there has been little accession of material to the Clay-with-Flints, except by a limited solution of the Chalk. Post-Glacial erosion must have destroyed a great deal of it, by widening all the valleys at the expense of the intervening ridges, until what were formerly large tracts of Clay-with-Flints have been reduced to the condition of small patches scattered over an area of bare chalk.

In conclusion, I gratefully acknowledge the assistance afforded me by Mr. William Hill, F.G.S., who has devoted much time and care to the weighing experiments and to the estimation of the residue from several samples of chalk. I also desire to thank Mr. H. J. Osborne White, F.G.S., for much useful information, as well as for specimens of chalk and Clay-with-Flints from near Wargrave. For other specimens and information I am indebted to Mr. Charles Griffith, F.G.S., Mr. C. J. Gilbert, F.G.S., Mr. J. Saunders, and the Rev. E. C. Spicer, F.G.S., as mentioned in the foregoing pages.

EXPLANATION OF PLATE VI.

Fig. 1. Section across Salisbury Plain and the Alderbury syncline. (See p. 150.)
2. Section from near Braishfield through Farley Down. (See p. 153.)

DISCUSSION.

Prof. BOYD DAWKINS said that he fully accepted the general conclusions at which the Author of this very interesting paper had arrived. The Clay-with-Flints was the result of the destruction of beds which were mainly, but not exclusively, Eocene. He (the speaker) had explored beds of similar nature and origin in the country round Chartres. The analyses cited by the Author agreed precisely with those which the speaker had made many years ago: in the lowest beds of the Lower Chalk the percentage of insoluble residue was the highest, diminishing from 20 to 5 per cent. as one approached successively-higher horizons. Very likely, the Clay-with-Flints was the outcome of work performed by geological agencies both during, before, and after Pliocene and Pleistocene times.

The Rev. EDWIN HILL enquired whether anything in East Anglia represented the Clay-with-Flints. If it was absent, the presence of Eocene Beds might support the views of the Author.

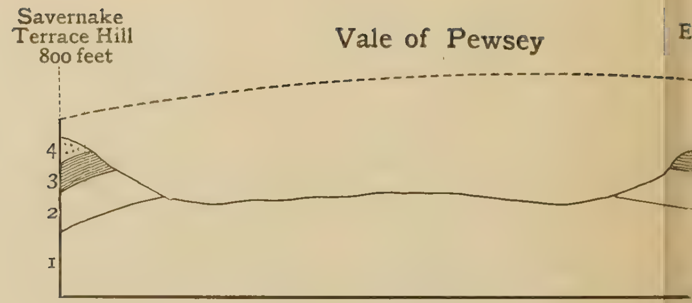
Mr. H. W. MONCKTON said he thought that no one could regard the deposits which it has been found convenient to map as Clay-with-Flints as, in the main, a residue from the slow solution of the Chalk: they undoubtedly consisted very largely of débris of Eocene strata. It appeared to the speaker that an explanation of the origin of the Clay-with-Flints, in order to be quite satisfactory, should also cover the deposits of brickearth which seemed to be so closely associated with the Clay-with-Flints, and reached an imposing thickness on the plateaux near Great Hampden and Caddington, for example.

Prof. SOLLAS said that he cordially congratulated the Author, and fully agreed with his results, which had anticipated his own. In support of them he cited the deposit at Stokenchurch, where the Clay-with-Flints contains fragments of Tertiary brown sandstone (identical with that of Nettlebed); also the occurrences in the neighbourhood of Ewell, where the Clay-with-Flints is seen to overlie Tertiary strata.

Mr. A. S. KENNARD said that his own observations on the North Downs entirely confirmed the Author's conclusions: but he could not admit that the Glacial Period had anything to do with the formation of the Clay-with-Flints, which must be earlier than the existing valleys.

Mr. G. W. YOUNG expressed his diffidence in addressing the Fellows on the evening of his introduction to the Society, and said that he only ventured to do so, because the subject was closely connected with the theory of dry Chalk-valley formation which he had advocated before the Geologists' Association in June last. He welcomed the Author's conclusions, because they strongly confirmed his own suggestion that a clay-sheet was once continuous over the

N.



Savernake
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Vale of Pewsey
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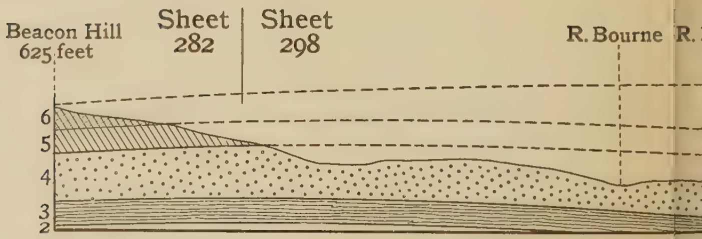
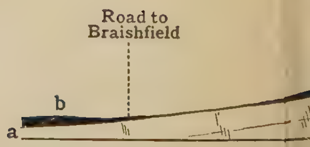
3
2
I



Beacon Hill
625 feet
Sheet
282
Sheet
298
R. Bourne
R.
6
5
4
3
2

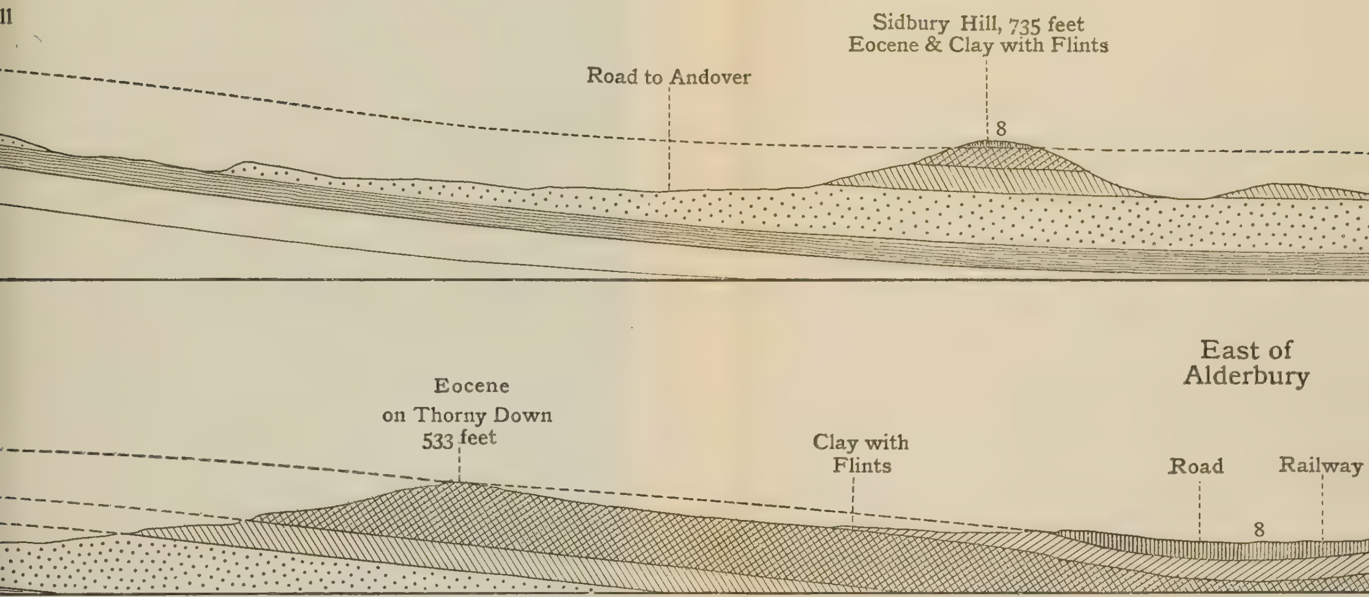
1 = Sel
2 = Lo

N.



Road to
Braishfield
b
a

Fig. 1.—*Section across Salisbury Plain and the Alderbury syncline.* *(See p. 150.)*

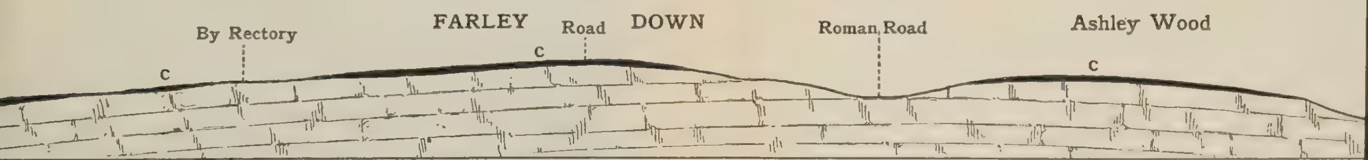


[Scales, horizontal: 1 inch = 1 mile; vertical: 1 inch = 1000 feet.]

tc.
.

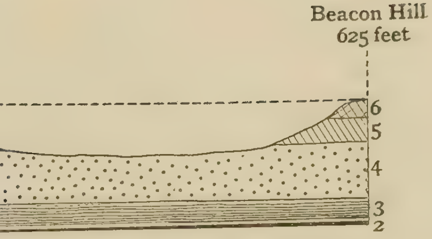
3 = Middle Chalk.
4 = Upper Chalk (lower zones).
5 = Zone of *Marsupites.*
6 = Zone of *Actinocamax quadratus.*
7 = Zone of *Belemnitella mucronata.*
8 = Eocene.

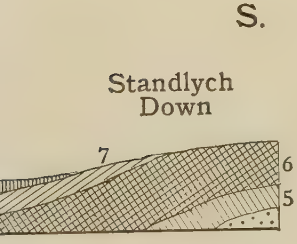
Fig. 2.—*Section from near Braishfield through Farley Down.* *(See p. 153.)*



[Scales, horizontal: 2 inches = 1 mile; vertical: 1 inch = 1000 feet.]

a = Chalk; *b* = Eocene; *c* = Clay-with-Flints.


Beacon Hill
625 feet
6
5
4
3
2


S.
Standlych
Down
7
6
5


S.
Road
a

North Downs, and showed that such a sheet was, not merely hypothetical, but highly probable. On the older theory of the Clay-with-Flints being the undissolved residue of the Chalk alone, he had always found it difficult to account for the large proportion of clayey matter present. The zone of *Micraster cor-anguinum* might certainly yield the flints, and possibly flints were necessary to hold the clay in place. If so, this would account for its absence over the northern part of the Chalk in Surrey, because this was now known to be largely the zone of *Marsupites*, which yielded very few flints. He believed that the overstepping of the Eocene strata was greater than the Author stated, as they rested at Worms Heath upon the zone of *Micraster cor-testudinarium*, and at Willey Heath, near the Caterham boring, upon that of *Holaster planus*.

Mr. Strahan asked for a definition of the term Clay-with-Flints.

Mr. S. Hazzledine Warren said that he was gratified to find his views, which he recently brought before the Anthropological Institute in another connection, so amply confirmed: those, namely, with regard to the kneading-together into a common mass of superficial beds of various ages and of different origin, during their gradual movement from higher to lower levels. With reference to Mr. Monckton's remarks on the brickearth of Caddington, it was worthy of note that this yielded Palæolithic implements of Moustérien age; while in Kent, certain very similar brickearths of the Chalk-tract yielded Neolithic remains, even to a considerable depth, including polished stone axe-blades, arrow-points of the usual types, and fragments of primitive pottery. Such rain-wash or stream-laid brickearths might, therefore, be of different ages, and have little in common with the Clay-with-Flints. He was quite unable to agree with Mr. Kennard that the hill-drifts must necessarily be older than the valley-drifts, as it was of the essence of the former that they should be formed on the hills, and not in the valleys. Ancient valley-drifts frequently capped the summit of the existing hills; but the true hill-drifts, in the speaker's opinion, were of different origin.

Mr. W. P. D. Stebbing, in referring to the superficial deposits on the North Downs south of Epsom, said that he had always taken the term Clay-with-Flints to mean a formation distinct from the jumble of materials which the Author included in his rendering of the term, and which might be a mixture of Thanet Sands, Woolwich & Reading Beds, and Blackheath Beds, or one or two of these redeposited. He understood by the term Clay-with-Flints a bed of stiff, usually red, clay with unrolled and practically-unbroken flints, resting upon and within swallow-holes in the Chalk, and occurring nearer the edge of the escarpment than the redeposited Lower London Tertiaries. He considered this bed to show distinct evidence of having been formed by a slow dissolving-away of the Chalk, and therefore of a different age from the worked-up mass of Tertiaries, which occurred rather farther from the edge of the escarpment and showed clear traces of a movement and rearrangement on a much larger scale than the

typical Clay-with-Flints. On the North Downs the movement of these superficial beds was still going on, and they were still to a certain extent being added to by the slow weathering of the existing outliers of the Tertiaries. With a higher water-level this was more rapid, and evidence of the extent of this denudation might be indicated by a bed of practically-clean unrolled flints in one of the dry valleys running northward from the edge of the Downs, which could not have been transported far, but for which the water-action was enough to carry away the clay wherein the flints were embedded.

Mr. Whitaker, who read the paper for the Author, prefaced his reply by alluding to his own connection with the Clay-with-Flints, which began in Berkshire, during the early days of his work on the Geological Survey. He was much troubled by the deposit, then little known, and at one time despaired of understanding it; but his depression was cured on finding that some of his senior colleagues had been led astray by this clay. The name used was unwittingly the same as that given by French geologists to a like deposit in France (*argile à silex*), and it was coined after work in Berkshire. That work was extended into neighbouring counties, and a theory of origin was then advanced. Later on, the work of mapping the Clay-with-Flints was greatly extended by the Geological Survey, both on the northern and southern sides of the London Basin, on the old series of maps. Still later, other tracts were surveyed, and the results published on the new series of maps; and it was to these tracts that the paper chiefly referred.

To Prof. Dawkins he replied that, while of course it was possible that some London Clay might have found its way into the deposit, in the area specially described by the Author the Reading Beds were generally a thick mass of clay, quite enough to account for so thin a deposit.

The answer to the Rev. E. Hill's query as to East Anglia, was that there was practically no representative of the Clay-with-Flints there, the occurrence of a wide and thick mass of Boulder-Clay having made its formation difficult, on any theory of origin.

As to Prof. Sollas's Clay-with-Flints over Eocene sand, Mr. Whitaker said that he should like to see the deposit, for he might be disposed to classify it otherwise.

Mr. Kennard's objection concerning the bringing-in of the Glacial Period, already called in to account for the gravels of the valleys, was met by the reminder that it was not the Author who had so called it in. Mr. Whitaker thought that the gravels in question might be post-Glacial, and so perhaps did the Author.

In conclusion, Mr. Whitaker considered that the Author had made out a good case, at all events so far as concerned the tract to which his remarks were chiefly confined, and he hoped that further investigation would be made in other areas, where there was a difference in the relations of the Clay-with-Flints to the Eocene Beds. He was always ready to learn from younger workers, who of course had the advantage of later information.

9. *The* Tarns *of the* Canton Ticino (Switzerland). By Edmund J. Garwood, M.A., Sec.G.S., Professor of Geology in University College, London. (Read June 7th, 1905.)

[Plates VII—XXI.]

Contents.

I. Introduction.

The study of lakes, so long neglected by geographers in the past, has of recent years received a great impetus from the investigations of Prof. Forel,[1] M. Delebecque,[2] Prof. Penck,[3] and other workers on the Continent, and of Prof. Russell,[4] Prof. Gilbert,[5] and Prof. W. M. Davis [6] in America; while in our own country, Dr. Mill,[7] Dr. Marr, Sir John Murray,[8] Mr. Pullar, and others have aroused our interest in this fascinating subject.

In his exhaustive 'Handbook of Limnology,' Prof. Forel remarks:—

> 'Each lake is an organism in itself, each has its peculiarities, its special history in the past and in the present, each deserves a special description. Hence the charm and also the scientific value which attach to the study of lakes in general and to that of each lake in particular.' [9]

Of all the numerous interesting branches of study connected with lakes, that of the origin of the hollow in which the lake occurs is the one that must especially appeal to the geologist; while of these hollows, those basins that are entirely surrounded by solid rock are certainly the most interesting and the most difficult to explain.

The theory, originally advanced by the late Sir Andrew Ramsay, and supported by Tyndall, Gastaldi, and de Mortillet, which would

[1] F. A. Forel, 'Le Léman' Lausanne vols. i–iii (1892–1901).

[2] A. Delebecque, 'Les Lacs Français' Paris, 1898.

[3] A. Penck, 'Morphologie der Erdoberfläche' pt. ii (1894) pp. 203–327.

[4] I. C. Russell, 'Geological History of Lake Lahontan' U.S. Geol. Surv. Monogr. xi (1885).

[5] G. K. Gilbert, 'Lake Bonneville' U.S. Geol. Surv. Monogr. i (1890).

[6] W. M. Davis, 'On the Classification of Lake-Basins' Proc. Boston Soc. Nat. Hist. vol. xxi (1882–83) p. 315.

[7] H. R. Mill, 'Bathymetrical Survey of the English Lakes' Geogr. Journ. vol. vi (1895) pp. 46, 135.

[8] Sir J. Murray, 'Bathymetrical Survey of the Freshwater Lochs of Scotland' Geogr. Journ. vols. xxii–xxvii (1903–1906).

[9] 'Handbuch der Seenkunde' Stuttgart, 1901, p. 9.

have us regard the majority of the large Alpine lakes as due to the direct erosive action of ice, has gradually given rise to a detailed consideration of the genesis of each individual lake.

At the present day, several eminent authorities still attribute the origin of some of the larger Swiss and Italian lakes to ice-erosion. Thus Prof. Brückner, in his recent work,[1] considers that the Lake of Zürich was created by glacial overdeepening, and that it represents the end of an old valley which was overdeepened by the Linth Glacier; he also attributes the formation of the Lakes of Zug and Lucerne to the same agency.[2] Prof. Davis again, in his paper on 'Glacial Erosion in the Valley of the Ticino,'[3] attributes the rock-basin of the Lago Maggiore to direct ice-erosion. It is evident, therefore, that this theory is in no wise extinct. On the other hand, many Swiss and Austrian geologists, notably Prof. Heim and Dr. Forel,[4] attribute all these lakes to post-Miocene earth-movements in one form or another. These lakes, which are of considerable size, all occur in the outer zone of the Alps, or the 'Kalk-Alpen' of Continental writers, and are often spoken of as 'Randseen' or marginal lakes. It is not, however, with these that I am at present concerned.

The lakes, the origin of which I intend to discuss in the present communication, are those to which in this country the name 'tarn' is frequently applied; they occur invariably in mountain-districts, and in the Alps are confined to the 'Hochgebirge.' They may be defined as lakes draining into the principal Alpine valleys, whereas the Randseen receive the drainage of these valleys.

These tarns, although they frequently occur as 'corrie'-lakes, include also others which, strictly speaking, do not come under this category. Of these latter, some are true rock-basins; while others owe their origin to the damming of valley-drainage by loose material.

Not long ago, Dr. Marr, in writing of the 'Tarns of Lakeland,' pointed out that many, if not all, of them were due to accumulation, and expressed a doubt as to whether any lakes of this class would eventually prove to be true rock-basins. Whatever may be the case in Cumberland, there can be no doubt of the occurrence of true rock-bound tarns among the 'Hochgebirgseen' of the Alps.

In the pages of the 'Geological Magazine' for 1898,[5] Prof. Bonney instanced a group of lakes in the neighbourhood of Airolo, which he unhesitatingly described as true rock-basins, and referred provisionally to excavation by ice; though, in the case of Lake Ritom, at

[1] A. Penck & E. Brückner, 'Die Alpen im Eiszeitalter' Leipzig, Lieferung 5 (1903) p. 525.

[2] *Op. cit.* pp. 537–88.

[3] 'Appalachia' vol. ix (1900) pp 151–52.

[4] A. Heim, 'Die Entstehung der Alpinen Randseen' Vierteljahrsschrift der Naturforsch. Gesellsch. in Zürich, vol. xxxix (1894) p. 66; and F. A. Forel, Bull. Soc. Vaud. Sci. Nat. ser. 3, vol. xxvi (1890–91) Proc.-verb. pp. xii, xvi & 'Le Léman' vol. i (1892) pp. 211 *et seqq.*

[5] P. 15 [not p. 45, as stated in the index of that volume].

all events, he 'saw difficulties.' A glance at the geological map of Switzerland shows that these lakes lie along the outcrop of certain Mesozoic limestones. It is also noticeable that, if traced westwards from the Airolo district, other lakes, such as the Engstlensee and the Trubsee, are found to be situated on the outcrop of the same rocks. Furthermore, it is obvious that many of the chief valleys and passes, such as the Val Bedretto and the Nufenen Pass, or again the Urserenthal and the Furka Pass, have been excavated along the strike of these calcareous rocks.

In noting these facts, I felt convinced that the occurrence of so many tarns along the outcrop of the same beds as those in which the valleys and passes had been excavated, must point to something more than mere chance coincidence. An especial interest attaches to these lakes, inasmuch as they include the group the origin of which Prof. Bonney has hesitatingly conceded to ice-erosion. I have, therefore, devoted portions of my summer-holidays during the past few years to their investigation.

I began work on the western group of lakes, which lie to the west and north of the Titlis. A preliminary survey showed that no definite conclusions could be reached, without some knowledge of the depth and general form of the lakes; none of these lakes, however, had been sounded, and this work yet remained to be done. One great obstacle presented itself to the immediate accomplishment of this preliminary step, in the fact that the majority of the tarns are destitute of boats. After consideration, I abandoned the idea of a portable boat, as the lakes are seldom free from wind after sunrise, and the accuracy of the soundings obtained from a drifting coracle seemed to me to leave a good deal to be desired.

Eventually, with the assistance of a grant from the Government-Grant Committee of the Royal Society, I succeeded in constructing a sounding-machine which could be used from the banks without a boat, capable of yielding very accurate results, being self-registering both as to the depth and the positions of the soundings. With this instrument I made a detailed survey of the group of lakes of the Val-Piora district, and later included other important tarns of the Canton Ticino. In the work of sounding these tarns I received great assistance from my friends, Miss Violet Wainewright, Mr. Haworth Moberly, and Dr. Ernest Kingscote, to each and all of whom I tender my sincere thanks, not only for the results that they accomplished, but for the way in which, by their ever-ready help and interest, they converted a somewhat tedious piece of work into a summer-recreation.

In the following pages I have endeavoured to bring together such facts as seem to bear on the origin of these lakes; but I have not yet had the opportunity of visiting all the tarns in the Canton Ticino, and my remarks must therefore be taken to apply only to those lakes which are actually described.

II. The Lakes of the Val Piora.

[Pl. VII—topographical map, facing this page.]

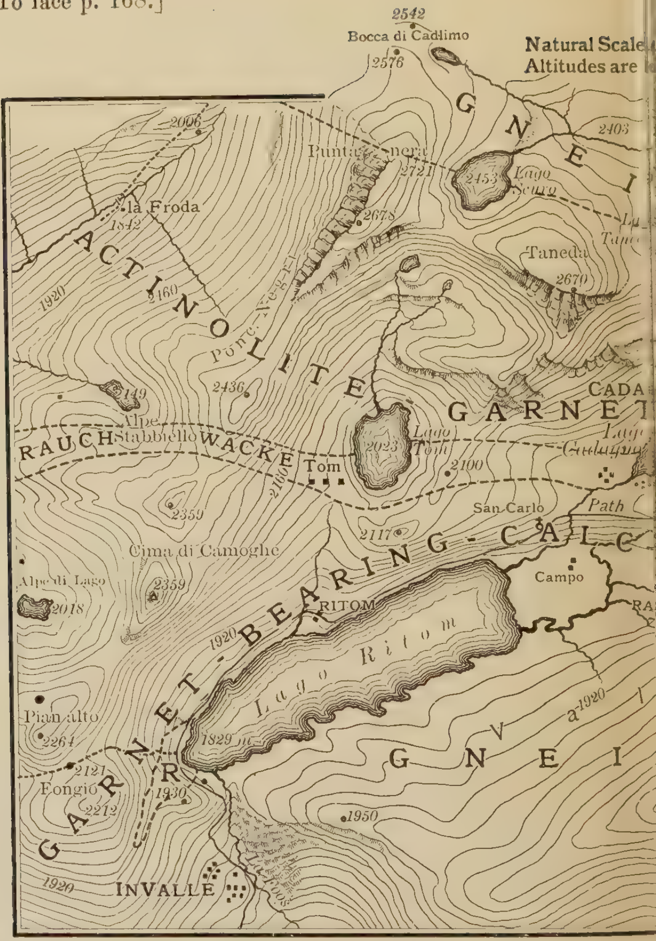
These lakes lie in a series of hollows in and around the mountain-glen of the Val Piora. This depression has been carved out of a series of limestones and schists, which have been squeezed in between two masses of gneiss—one of these forming the northern wall of the Val Levantina below Airolo, and the other constituting the Val-Cadlimo district on the north. That the majority of these lakes occupy rock-basins is clearly shown in Prof. Bonney's careful description.[1] I will reserve any further general remarks until I have described the lakes in detail, when we shall be in a better position to discuss the evolution of the district as a whole.

Lago Ritom (see Pls. VII, VIII, & XVI) is situated exactly 6000 feet above sea-level, and occupies a true rock-basin. It has a length of about 2190 yards, and a width (at the upper end) of some 590 yards, becoming narrower towards the exit. It is fed chiefly by three streams, namely, the Murinascio torrent, draining the Val Piora, and the two streams carrying the overflow from Lago Tom and Lago Cadagno respectively. These last-named lakes receive the drainage from two unnamed tarns, to which, for convenience, I shall refer as Lago Taneda and Lago di Murinascio. The former (namely, Lago Taneda), which lies on the watershed, drains southwards through the Lago Cadagno. Lago di Murinascio has no true exit; any surplus-water that there may be finds its way through the screes which form the lowest point of its containing barrier. Lago Ritom must once have extended nearly 1000 yards farther to the north-east, over the area now occupied by a delta which forms a swampy alluvial flat; a delta which, from its peculiar situation, might well be used to ascertain the length of time that has elapsed since the close of the Glacial Period in this district. The southern shore of the lake is formed of coarse foliated gneiss, dipping north-north-westward at about 35°; while the northern bank runs along the foot of a steep escarpment of calcareous crystalline schists—a complicated series, much folded, contorted, and crushed. At the south-eastern corner of the delta, outcrops of rauchwacke and dolomite occur; and the same beds must form the floor of the lake throughout its length, for they reappear at its western end, where they are found cropping out close to the Hotel, while beds of a similar calcareous character occupy most of that end of the lake in places up to the 1980-metre contour. As this fact is not at all clear from Dr. K. von Fritsch's map, where only a small patch of rauchwacke is shown, forming the saddle between Pian' Alto and Fongia, a brief description of the rocks that occupy this end of the lake is necessary.

Starting from the exit of the lake, we find the water of the Foos running out over the southern mass of gneiss. This rock can be

[1] Geol. Mag. 1898, pp. 15 *et seqq.*

To face p. 168.]

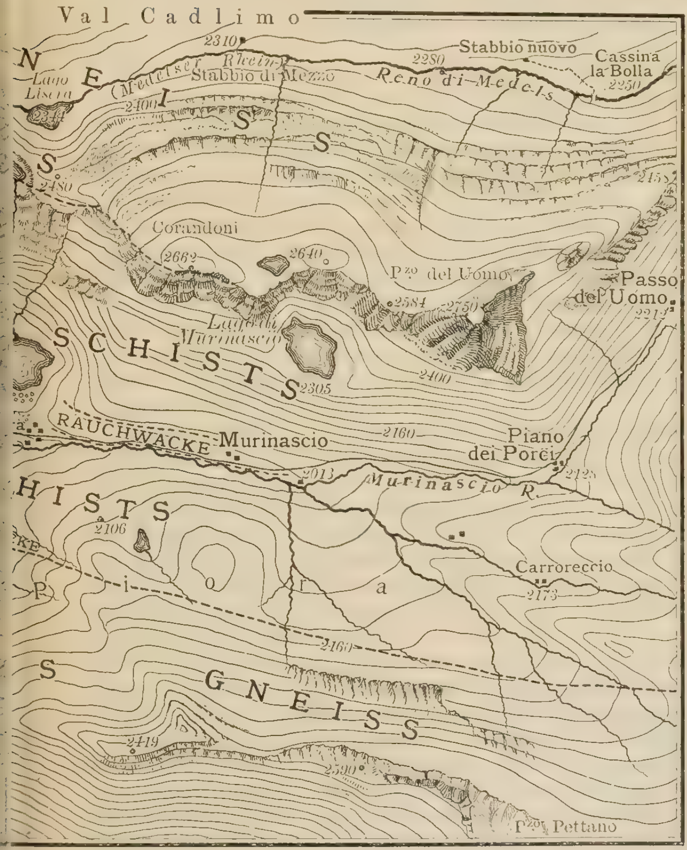


Map of

[A triangular patch of rauchwacke should have been indicated in
the occurrence of gypsum should have been indicated jus

ed in metres.

The Val Ticino lies just outside the map, below it; & the Val Canaria lies also just outside the map, sensibly parallel with its Western margin.



Piora Lakes.

[...me left-hand corner of the map, between Pian alto and Fongio. Also ...be numerals of altitude 2013, north of the Murinascio stream.]

followed for a few yards past the Hotel to a point where the path to Pian' Alto turns up to the left. Here the gneiss dips under the end of the lake, and is not again seen; north of this no outcrop of rock in place is met with, until we reach a conspicuous gully which ends in a well-marked delta, the broad depression that intervenes being obscured by fallen talus. If, however, we turn up the path to Pian' Alto, we find that the gneiss is immediately overlain by a bed of pale pink rauchwacke, closely resembling in texture the rock which crops out at the south-eastern end of the lake.

The junction between the gneiss and the rauchwacke runs almost along the track leading to the little knoll behind the Hotel, marked 1930 m. in the Swiss Government map (see Pl. VII); in fact, the track has taken this line up the dip-slope of the gneiss, on account of the depression formed by the unequal weathering at the junction of these two rocks. From here the outcrop of the calcareous rock can be traced northwards, across the scree-covered depression, to a conspicuous bluff occupied by a small plantation of nine fir-trees. Here the rock is rather lighter in colour and much honeycombed, and closely resembles the rock surrounding the exit-end of Lake Tom. Masses of this rock are found in the gully-section farther north; and it crops out again farther on, by the side of the path running round the north-western edge of the lake (see Pl. XIII, fig. 1).

If we now follow the upper portion of the outcrop, south from the tree-covered bluff, we find a conspicuous band of the same rock, 40 to 50 feet thick, running for some distance round the eastern flank of Fongio, behind the 1930-metre hill, and dipping at some 6° to 10° northwards in the neighbourhood of the 1980-metre contour-line. After continuing for some distance in this direction, it ceases abruptly. It is found, however, a few yards below, on the path running round the hill into the Val Canaria. An analysis of this band is given below (p. 177).

The rock is everywhere micaceous, and in places contains large tufts of actinolite, which appear to be arranged roughly along certain planes. A good section, showing nests of actinolite-crystals, is exposed in the little quarry at the back of the Hotel.

It will be seen, then, that from the edge of the gneiss the western end of Lake Ritom is composed of calcareous rocks, up to a height of 1980 metres. The abrupt disappearance of this mass at either end of the outcrop is very suggestive; and we may, I think, regard the area occupied by Lake Ritom as a large lenticle of calcareous rock, possibly including a bed of gypsum, enclosed between the gneiss on the south and the crystalline schists on the north.

An interesting feature is brought out by a comparison of the northern and southern shore-lines of the lake. The former, disregarding the scree and delta-material, is seen to run in a straight line along the length of the lake; the latter, on the other hand, is broken by numerous bays and rocky headlands (see Pl. VIII).

The surface of the southern mass of gneiss, as shown above, can

be traced westwards under the calcareous rocks on the north side of the 1930-metre hill. It represents therefore almost exactly the former line of junction of this gneiss with the overlying rauchwacke, now removed by denudation over the area occupied by Lake Ritom; and the existence of the bays and headlands seems in some cases to have been determined by folds or crumplings, which must once have affected both sets of rocks, as will appear by an inspection of the bathymetrical contours. Some of the bays, however, are due to stream-erosion, as shown by the abruptly-truncated strike.

The general shape of this lake-basin is indicated on the bathymetrical chart (Pl. XVI). The greatest depth met with was 163 feet, in the centre of the lake. The greater part of the lake is over 100 feet deep; while an area, about 330 yards in length and 150 feet or more in depth, occupies what must originally have been the centre of the lake, if we allow for the portion at the upper end which is now filled with delta-material. The floor of Lago Ritom is thus seen to form a very symmetrical trough, the axis of greatest depth running east and west, practically down the middle of the lake. The contours near the southern side are influenced by the subaqueous folds of the gneiss for some distance from the shore. The contours along the northern bank bear no particular relation to the subaërial escarpment, being chiefly influenced by landslips and rock-falls from the steep cliffs above: were it not for the loose material thus accumulated, the northern shore would undoubtedly descend much more steeply than it now does.

Lago Tom (see Pls. IX, X, XII, & XVII).—This lake lies at an elevation of 6637 feet above the sea. It occupies a hollow directly above, and to the north of, Lago Ritom. In shape it is a rough oval. Its greatest length from north to south is exactly 550 yards, and its greatest width from east to west about 350 yards.

Prof. Bonney remarks in a footnote (*op. cit.* p. 19):

'Its area is given as 1000 square metres, and it is said to be shallow. But I should think it would not be less than some 20 feet deep, and might be more.'

The greatest depth that I obtained was exactly 50 feet. The lake, again to quote Prof. Bonney:

'occupies a kind of cirque, and lies in the strike of the same rocks [as Lago Cadagno], for the enclosing crags consist of similar amphibolitic and granatiferous gneiss, and at the lower end is rauchwacke, which can be traced from the southern side of the basin of the Lago Cadagno across the intermediate spur.'

The lake terminates at its southern end in a wall of rauchwacke, about 16 feet high. A short gorge leads into the heart of the rauchwacke, near the eastern end of this wall; and after heavy rain, when the lake is high, I have seen the water flowing through this channel and disappearing underground. It reappears as a spring farther west, on the south side of the barrier of rauchwacke, exactly at the junction of that rock with the underlying schist. After a spell of fine weather the level of the lake falls so that the

water does not reach the channel, and a broad, flat beach is laid bare at the south-western end of the lake; the spring, however, continues to issue at the same spot. This 'terminal' wall of rauchwacke is rotten and honeycombed, and just above the spot where the spring now issues is situated a large cave which evidently represents the old source of the spring, when it escaped higher in the rauchwacke (see Pl. XII, fig. 1). Apparently it has gradually dissolved its way down to the level of the insoluble schist, against which it is now thrown out. The rock is a fine-grained metamorphosed limestone containing some 16 per cent. of dolomite, and 8 per cent. of insoluble material, chiefly silica.

The bathymetrical chart (Pl. XVII) shows the general shape of the lake-floor. The maximum depth of 50 feet is situated about one-third of the way from the northern end of the lake. The axis of greatest depth runs east and west, and passes through this point. It is parallel to the strike of the rocks, and appears to coincide with the junction of the rauchwacke and the overlying crystalline schist. The shore of the lake is entirely formed of delta-material and sand, with the exception of the southern wall of rauchwacke described above. But for this the upper end of the lake would, as in the case of Lago Ritom, undoubtedly show deeper soundings near the northern shore. The flat shallow bay occupying the southern end between the delta and the exit-channel has an average depth of about 3 feet, and is strewn with fragments of minerals, many of them presumably derived from crystalline schists. These coarser fragments must have been brought down by the stream descending between the rauchwacke and the overlying schists; and it is a very suggestive fact that, although fragments of mica clearly derived from the rauchwacke are represented, no pebbles of this rock are found, despite its occurrence here *in situ* round the end of the lake.

Lago Cadagno (see Pls. XI & XVIII) lies due east of Lago Tom, at the somewhat lower level of 6302 feet. It is situated apparently on the strike of the same beds (namely, the rauchwacke on the south, and the overlying crystalline schists on the north), and occupies a slight synclinal depression. It is surrounded by alluvium and scree-débris, with the exception of the north-eastern corner, where solid rock occurs, and the southern bank, where the rock is plastered with morainic material. The lake doubtless once extended to the rocky barrier over which the river now falls into Lago Ritom; but the western end has been filled up by material washed down from the steep escarpment on the north and north-west. It is possible that it once drained from its south-eastern end. The lake is 875 yards long and about 330 yards in width, the greatest depth being 62 feet. The bathymetrical chart (Pl. XVIII) shows that it is a symmetrical spoon-shaped hollow, having an axis of greatest depth running east and west, parallel to the length of the lake, situated nearer to the northern than to the southern shore. It is fed by a group of some ten or twelve streams which cascade down the precipitous scarp-face on the north. Most of these originate in

patches of snow, which lie throughout the greater part of the year in hollows near the watershed; but one, the lowest, occupying the centre of the cirque, originates in the little Lago Taneda mentioned on p. 168. This cirque is a good example of an escarpment-cirque, formed by a series of streams which derive a constant supply from lakes and melting snow. The water from Cadagno winds through the alluvial and morainic material mentioned on the previous page, to the edge of the rock-escarpment of quartz-calc-garnet schist; but the fall is very slight, probably not more than a few feet. The rock-basin of Cadagno must, therefore, be at least 50 feet deep. From the edge of the escarpment the water plunges abruptly into the Ritom basin, down a cliff 100 feet high, near the centre of the synclinal fold.

Lago Scuro (see Pls. XII & XIX) is undoubtedly one of the most interesting of the lakes in this district. It lies at a height of 8048 feet, and is situated almost on the watershed between the Ticino and the Reno di Medels (or Medelser Rhein), its exact position being some 150 or 160 feet below the summit of the ridge on the northern side. It drains through the Val Cadlimo into the Medelser Rhein, and occupies a true rock-basin, which lies along the junction between the schist and the northern mass of gneiss.

It is roughly oval in shape, and has a longer diameter of 404 yards, which runs north-north-east and south-south-west. The only drainage that it receives is derived from the melting snow round its sides, and it discharges its surplus water down a rocky channel into the Cadlimo River. The bathymetrical chart (Pl. XIX) shows it to have a maximum depth of 138 feet. The contours run roughly parallel to the shore, and the axis of greatest depth lies east-north-east and west-south-west, in the general direction of the junction of the gneiss and the crystalline schists. The shore is entirely formed by rock *in situ* with occasional loose blocks, while a patch of snow permanently occupies a portion of the eastern bank. The dip of this schist is about 40° northward, but it can be seen sweeping round in a basin-like curve across the southern end of the lake. Soundings show that ridges of rock continue under water for some distance out, and thin bands of harder material have weathered out so sharply as to cause considerable trouble in using the sounding-line.

Lago Taneda (for contour-map, see Pl. XX) occupies a rock-basin, lying at a height of 7740 feet, and is situated along the same line of strike as Lago Scuro. According to Dr. Fritsch, who mapped the district in detail, the junction between the northern mass of gneiss and the underlying schist runs down the middle of the lake. The relation between these rock-masses at the exit is not very clear; but the gneiss is well seen, forming the watershed above the north side of the lake, where it appears to be iceworn. The southern shore is formed of a gneissose mica-schist dipping about 40° northward; but immediately below this, on the track leading

down to Lago Cadagno, an outcrop of black hornblende-schist occurs. The rocks forming the shores of the lake are jagged and broken, and show no signs of ice-abrasion. The cliff of gneiss above the northern and eastern shores is interrupted and broken down towards the north-west, where a low col leads over into the Val Cadlimo. The lowest point of this col lies some 150 feet above the present level of the lake. Another, but less well-marked depression, leads from the spring on the north-western shore to a small pool, which drains into the Lago Lisera in the Val Cadlimo.

Lago Taneda is, therefore, situated as nearly along the watershed as may be, and it is probable that it drained at some former time over one or both of these gaps into the Val Cadlimo; possibly during a temporary obstruction at the present outlet, or before it had been cut down to its present depth.

The greatest length of the lake from east-south-east to west-north-west, along the line of strike, is 490 yards; and the greatest depth is 140 feet, practically the same as that of Lago Scuro. The bathymetrical chart (Pl. XX) shows that the greatest depression is situated towards the western end of the lake, while the narrower south-eastern end forms a shallow bay. There is, however, a general axis of greatest depth running along the length of the lake parallel to the strike of the rocks, which probably coincides with the junction between the gneiss and the schistose rocks.

Lago di Murinascio, alone among the tarns in this district, is situated wholly in one set of beds. It lies at a height of 7562 feet, and occupies a corrie in the northern wall of the Val Piora, above the Murinascio Alp. It belongs to the upper group of lakes represented by Lago Taneda and Lago Scuro. The lake is not entirely rock-bound, the water at the lower end being held up by scree-material. No soundings were made, as this lake is not a true rock-basin, and there is no exit. A ridge of rock, however, forms the shore on the south side, and it may possibly be a shallow rock-basin.

Lago Lucomagno, situated in a corrie on the south-western flank of the peak of that name, is partly scree-dammed, but must be a rock-basin some 40 feet deep. It drains directly into the Ticino below Varengo, but in this case, as in that of Lago Tom, there is no overflow. A spring (which issues some 500 feet below) appears, however, to derive its supply from this lake. The lake is almost divided into two separate sheets of water by a narrow peninsula. The water at the lower end is partly held up by rock-falls and screes, and partly by rock *in situ*, and is situated along a strike-ledge in the gneiss. The depression which the lake occupies can be seen continuing as a line of weakness to the east, where it is weathered out into a gully in the hillside.

A little tarn, not shown on the Government map, occurs on the northern slope of the same mountain, but it is obviously due to a landslip, and does not require our further attention.

Lago Camoghè, lying on the western slope of the peak of that name, is another example of a scree-dammed tarn. Its formation may, however, have been influenced by the occurrence of a bed of rauchwacke, which occupies the pass between Pian' Alto and the Cima di Camoghè. This rock, although not so shown in Dr. K. von Fritsch's map, appears to strike round the south-western end of this lake, and reappears at the head of the gully at a point where the spring issues a little below the Alpe di Lago.

The Origin of the Piora Lakes.

So far as I am aware, only one writer on this district has expressed any opinion regarding the origin of these lakes, namely Prof. Bonney, in his paper in the 'Geological Magazine' for 1898, already quoted.[1] In discussing the possibility of their formation by ice-erosion, he does so, evidently, with a desire to give all due weight to a theory which is perhaps that most generally held in regard to the formation of lakes of this class; but he is obviously not quite satisfied, himself, with the application of the theory to these particular lakes. I will, in the first place, point out the serious difficulties in the way of accepting this theory, and afterwards suggest what seems to me a more probable mode of origin.

Let us first take Lago Ritom. In the case of this lake, there are only three directions in which ice can reasonably be assumed to have travelled, namely: (1) from the depression between Pian' Alto and Fongio at the western end of the lake; (2) from the district on the north, now drained by Lago Tom; (3) from the Val Piora on the east, including possibly a tributary from the cirque now occupied by Lago Cadagno (see Pls. VII & XI).

In the first case, there would be no sufficient gathering-ground inside the Ritom drainage-area, and ice advancing from this quarter must have originated outside the district and overtopped the western watershed; but we have no evidence of an accumulation of ice in the district to this depth, and had the ice in the Val Ticino reached to this height, it would have invaded the Ritom basin much more readily from the east through the present exit of the lake, which is nearly 1000 feet lower.

The second case postulates a glacier descending from Lago Tom. This could not possibly have excavated the upper end of Lago Ritom, and consequently this supposition may be at once dismissed.

There remains only the third alternative, namely that of a glacier descending the Val Piora, augmented possibly by ice from the Lago-Cadagno basin. There can be no doubt, I think, that this district lay above the snow-line during the Pleistocene Period, and that snow and ice accumulated here and occupied the Val Piora. My difficulty lies in understanding how this ice could acquire any velocity in moving westward along the basin now occupied by Lago Ritom, and why it should have turned off at right angles and discharged itself to the south-east, unless these lines of drainage had been previously determined.

[1] But see also A. Delebecque, Comptes Rendus Acad. Sci. Paris, vol. cxxxix (1904) pp. 936 *et seqq.*

Prof. Bonney remarks (Geol. Mag. 1898, p. 20) :—

'Supposing a glacier to be descending the Piora valley, we must assume this wall [at the north-eastern end of Lago Ritom] to be already in existence, or it could not acquire any plunging force, and even then the fall seems hardly adequate to produce the erosion of a basin like that of Lake Ritom. Possibly, however, the ice, just at this part, may have been "jammed"; for the main glacier was probably augmented by another ice-stream, which descended a shallow, but fairly well-marked valley, leading from a gneissic peak lying south-east down to the corresponding corner at the head of the Ritom basin; while the narrow "gate" by which the water is now discharged towards the Val Bedretto would block the mass of ice above it, and this would produce more than usual friction on the bed of the valley now occupied by the lake and its delta. This basin then, the part which lies below the present contour-line of 6000 feet (in round numbers), is the utmost that, in my opinion, can possibly be attributed to the erosive action of ice. Of this action all the other dominant features in the surrounding scenery exhibit nothing more than superficial traces, and they appear to be due to the usual meteoric agencies.'

It is this probability of the ice becoming 'jammed' at the western end of Lago Ritom which would, I think, prevent it from excavating to any appreciable extent. In a former paper, read before this Society by Prof. Gregory and myself,[1] we showed that where the lower layers of a glacier are embayed, their advance is practically checked, and shearing of the upper layers takes place over those below. Under these circumstances the greatest erosion, in the case that we are considering, would be on the surface of the rock-lip near the present exit of Lago Ritom, and it is precisely here where we find the most obvious indication of former glacial abrasion. Such erosion would, therefore, tend to destroy a rock-basin, not to produce one. Again, the presence of the rocky headlands, which have been described as occurring along the south side of the lake, jutting out to the north-west, should have protected the rauchwacke, originally occupying some of the present low bays, from ice coming down from the east; but not a trace of the rauchwacke is to be found there. So far, therefore, as Lago Ritom is concerned, it does not seem easy to account for the excavation of the basin which it occupies on the supposition that it was ice-eroded.

If we turn to the other lakes, Tom and Cadagno, the difficulty is increased. It is obvious that these lakes could not have been excavated by a glacier descending the Val Piora, and no glaciers could have formed on the nearly-vertical cliffs which hem them in to the north. If we postulate ice, other than local accumulations of snow, we must, as shown above, bring it from outside the basin. In this case it must have come over a watershed 8200 feet high, and there is no proof of the country having been swathed in ice to this enormous depth. But, supposing such ice to have poured down from the heights to the west, why, after digging out Lago Tom, did it ascend the slope of rauchwacke between Lago Tom and Lago Cadagno, only to dig Lago Cadagno again, out of the same material and along the strike of the same rocks?

Or, again, assuming that the ice poured over the watershed, down the precipices which hem in the lakes on the north, it could only have arrived at the bottom in fragments, and could at the most have contributed to a remanié glacier.

[1] Quart. Journn. Geol. Soc. vol. liv (1898) pp. 203 *et seqq.*

Lastly, if the ice came from the north, how was the Lago Scuro excavated, or the Lago Taneda, which is entirely shut in by precipices on the north? It is, indeed, extremely difficult to account for the excavation of these last-named tarns by ice, even if we attribute to that agent the utmost power that has ever been claimed for it.

Let us take the Lago Scuro as a crucial case. Here is a rock-basin 136 feet deep, situated almost on a main watershed, within a few metres of its summit, and surrounded on three sides by steep cliffs. There is no gathering-ground above it for a glacier, and it is thoroughly protected from any ice invading the region from outside: yet we find a rock-basin of this considerable depth. I need hardly add that the steep reefs of rock running into the lake are quite inconsistent with ice-erosion. The case of Lago Taneda is still more difficult. No ice could possibly reach this lake from anywhere except a little névé from Taneda, and yet it is a deep rock-basin.

Geological Structure.—Putting aside, then, the theory of ice-erosion, we must seek for some other reason for the existence of these lakes.

Let us first of all consider, in rather more detail than we have yet done, the geological structure of the district.

All the rock-basins of this group, as shown above, are situated along the junction of two distinct types of rock. The three lower lakes lie along the strike of two nearly-parallel outcrops of rauchwacke and dolomite, and occur at the junction of these rocks with gneiss and crystalline schists.

A glance at Dr. K. von Fritsch's map shows, not only the lower lakes, but also the valley of Piora running along the outcrop of the rauchwacke and dolomite, while the same rocks occupy the two passes leading into the Val Canaria between Fongio, Pian' Alto, and the Cima di Camoghè. We have, therefore, in this district differential erosion depending on differences in geological structure, being greatest along the rocks rich in calcite and dolomite. In addition to this, the soundings show that the axes of greatest depth of all the lakes lie along the junction of calcareous and crystalline rocks.

The causes which produced the peculiar geological structure of the district still remain to be considered. In his well-known paper, 'On the Crystalline Schists & their Relation to the Mesozoic Rocks in the Lepontine Alps',[1] Prof. Bonney has argued against the inclusion of the rauchwacke and dolomite in the same metamorphic series as the crystalline schists occurring above and between them. He regards them as an entirely-separate group of rocks, introduced among the crystalline series by faults or thrusts, and rejects the idea suggested in the sections accompanying Dr. K. von Fritsch's map, that their present relation to the schists is the result of simple folds, which affected a stratigraphically-continuous series of beds.

After my first visit to the district, and before I had seen Prof. Bonney's paper, I had arrived at precisely the same conclusion; a conclusion which has been fully corroborated by subsequent ex-

[1] Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 187.

amination. I found it no easy task to locate the exact dip and horizon of these planes of movement: in fact, the beds have been more crushed and rolled out than even Prof. Bonney himself, I think, imagined. Not only are there undoubted lines of movement between the crystalline rocks and the beds of rauchwacke, but, for some distance from the schists, fragments of the latter rock have been torn off and incorporated in the calcareous beds. In the lower part of the schists again, between the two lakes, eyes of calcite and dolomite have been rolled out and included in the crystalline schists; and it is possible to collect from the western end of Lago Ritom a series of specimens, ranging from pure rauchwacke to a foliated rock consisting of alternate layers of rauchwacke and schist. The whole process must have been analogous to what I have seen taking place in the case of advancing Arctic glaciers. Here not only are thrust-planes formed by the continual retardation of the lower layers of the ice, but, owing to the presence of shear-planes, fragments of the underlying material are dragged out along them and arranged in a roughly-stratified manner throughout the ice; many of these are even raised by this process for considerable distances above their source of origin.

We may, I think, then conclude that, so far as the valleys in which the lakes lie are concerned, their formation has been determined by the presence of thrust-planes, and that, in the case of the valleys in which the three larger lakes occur, the effect of these thrusts was emphasized by the introduction of wedges of softer rock.

The overdeepened portions of the valleys in which the lakes occur still, however, remain to be accounted for. They cannot, of course, be due to ordinary mechanical erosion by the present stream; but the special character of the rocks seems to suggest that the chemical action of water may have manifested itself in an unusual degree, owing to the relatively-greater solubility of the calcareous rocks. Analyses of three samples of the rauchwacke have kindly been made for me at University College (London) by Miss Edith Goodyear, B.Sc. These were collected from the barriers of rauchwacke rising from the southern end of Lago Tom and the western end of Lago Ritom respectively. I have added for comparison a fourth analysis, made by Dr. Grubenmann, of the same dolomite where it crosses the Val Canaria.[1]

	I.	II.	III.	IV.
CO_2	39·21	39·30	41·88	44·96
CaO	45·61	45·41	41·90	40·12
MgO	4·10	3·83	8·80	11·96
SiO_2	—	1·19	—	—
Fe_2O_3	1·34	2·01	1·28	0·42 FeO
Insoluble residue	8·10	7·87	6·04	1·96
Totals	98·36	99·61	99·90	99·42

No. II is from the broken-down underground channel described above. It was especially selected, on account of the relatively-large amount of green mica which it contained; while No. I is an average sample of the rauchwacke. No. III was collected from the cliff of rauchwacke cropping out on the east side of Fongio.

[1] See Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 230.

The solubility of the rock is shown by its crumbly and cavernous character where it is exposed at the surface (see Pl. XII, fig. 1), and by the fact, mentioned above, that the surplus-water from Lago Tom, instead of finding an exit over the rauchwacke, dissolves its way underground and reappears exactly at the junction of the rauchwacke with the underlying insoluble schist.

Experiments prove that the rock is rapidly disintegrated by water containing carbon-dioxide in solution. Miss Goodyear finds :—

	Per cent.
Soluble in cold dilute hydrochloric acid	75·8
Soluble in hot dilute hydrochloric acid	92
Soluble in $H_2O + CO_2$	11 in 45 hours.

Assuming the difference between the solubility in hot and cold acid to be due to dolomite, the composition of the rock would be as follows :—

$CaCO_3$	73·4
Dolomite	16·2
Fe_2O_3	1·3
Insoluble residue	8·1
	99·0

Microscopic examination shows how this solubility is assisted by the granular structure of the rock, which readily falls to pieces so soon as the crystals of calcite are dissolved.

Being impressed, when sounding these lakes, with the possibility of their having originated from solution of the rauchwacke, I dredged several samples of the deposits from the floor of Lago Tom and Lago Cadagno. These were taken from their southern sides, where the deposit overlies the outcrop of the rauchwacke. They consist, in both cases, of coarse fragments of various minerals mixed with a fine white micaceous sand. The coarser fragments are composed of quartz, garnet, actinolite, and mica, derived from the crystalline schists above, and washed into the lakes by streams from the north. The finer material, after sifting through a sieve of 80 meshes to the inch, consisted of little rounded grey grains, together with a few flakes of mica, etc. On boiling in dilute acid, the former dissolve readily, and prove to be dolomite-grains, which have fallen on to the floor of the lake after the solution of the calcite and the disintegration of the rauchwacke. This finer material, therefore, represents the less-easily soluble residue of the rauchwacke. The collection of the dolomite-grains into one sieve is due to the wonderfully-uniform grain of the recrystallized rock. With the view of further testing the solubility of this rock, I collected samples of the water from Lago Tom and Lago Cadagno.[1] The samples were collected where the water

[1] Taken after a week of very heavy rain.

flowed out of the lakes. These are found to contain total solids :—

Lago Tom	·0733 gramme per litre.
Lago Cadagno	·1260 ,, ,,

A qualitative analysis showed that the solid salts consisted of lime and magnesia, with a little iron and alumina. In the case of Lago Cadagno especially, a great deal of sulphuretted hydrogen was discharged when the mud was disturbed on the bottom of the lake, and the sounding-line and plummet, when drawn to the shore, always smelt strongly of this gas. The same phenomenon was noticeable in the case of Lago Ritom, but I never noticed the presence of sulphuretted hydrogen in the mud from the floor of Lago Tom.

There can be little doubt, I think, that the presence of this gas in such quantities in the deposits of Lago Ritom and Lago Cadagno, and its absence from Lago Tom, must be attributed to the presence of fishes in the two former lakes and their absence from the last-named. While the two former are stocked with trout, all attempts to rear trout in Lago Tom have failed, and this failure is attributed by M. Lombardi to the presence of lime in its waters.

[In this connection the investigation of MM. André Delebecque & Ernest Bourcart on the waters of certain Alpine lakes is full of interest.[1] M. Bourcart finds in the bottom-waters of Lago Ritom 2·365 grammes of dissolved salts per litre, including the following salts :—

		Grammes.
SiO_2	=	0·010
CaO	=	0·737
MgO	=	0·1962
SO_3	=	1·3767
K_2O	=	0·0042
Na_2O	=	0·0027
$Fe_2Al_2O_3$	=	0·0012

The surface-water, on the other hand, contains only 0·140 gramme per litre of dissolved salts; and the three affluent streams from Lago Tom, Lago Cadagno, and the Val Piora contain a mean of 0·139 gramme per litre (*op. cit.* p. 937).

The authors are probably right in concluding that the great increase in dissolved salts found in the bottom-waters is due to underground springs, which enter the lake through the soluble rauchwacke. It might be urged that the salts had accumulated at the bottom by degrees, owing to the formation of ice in winter and the consequent concentration of the salts in the surface-water, which would thus have its specific gravity increased, and, being at the same time cooled down, would be compelled to descend. An interesting point in this connection is, however, brought out by the temperature-determinations made by these authors at different

[1] Comptes Rendus Acad. Sci. Paris, vol. cxxxix (1904) pp. 936 *et seqq.*

depths. They find that anomalies of temperature occur, similar to those discovered by M. Venukoff in the Black Sea. With a surface-temperature of 13·2° C. a gradual decrease takes place until a depth of 33 feet is reached, where a minimum temperature of 5·1° is found. Below this, the temperature gradually increases until the bottom is reached, where, at a depth of 144 feet, the temperature is found to be 6·6° C. This rise of temperature in the bottom-waters of the lake appears to me to point to underground springs as the cause of concentration of salts in the lower layers, rather than to the sinking of concentrated surface-water in winter.

Another interesting point is brought out by the presence of a large quantity of sulphuric acid in the deepest layer of Lago Ritom. The authors attribute the presence of this acid to the solution of gypsum, but there is no bed of gypsum recorded among the rocks which crop out round the lake. It will be seen, however, that the bed of rauchwacke shown on Dr. K. von Fritsch's map, as running from Pian' Alto into the Val Canaria, includes large beds of gypsum where it thickens out to the west; and that, if Lago Ritom occupies the site of a similar 'eye' of rauchwacke, it is highly probable that this eye includes beds of gypsum as well as rauchwacke, for it lies along the same line of strike. In this connection, the total absence of sulphuric acid from the waters of Lago Tom is a highly-suggestive fact.

The analyses, then, of MM. Delebecque & Bourcart seem to confirm the idea that Lago Ritom owes its origin, in part at all events, to solution.]

Although the presence of these lakes appears to depend chiefly on the structural peculiarities described above, accompanied, in some cases at all events, by solution, there is one remarkable feature in the drainage of the district on which I have only briefly touched: I refer to the way in which Lago Ritom is surrounded by hanging valleys. Not only is this the case with all the three streams flowing into it, but it is still more marked in the case of the La Foos torrent, which flows out of the lake, and carries away the whole of the drainage of the Val Piora. This torrent plunges by a series of cascades 2700 feet down into the Ticino River, at an average slope of 1 in 2·6. As I have shown elsewhere, this torrent forms one of a series which drain from hanging valleys into the Ticino as a consequence of the overdeepening of the main valley. While other valleys, such as the Val Canaria, have adjusted themselves to the Ticino, the Val Piora has been prevented from doing so by the presence of the lake, which has arrested erosion by holding up the solid particles on its floor.

Let us trace the history of the Piora drainage a step farther back.

A glance at a model or map of the district shows that La Foos is obviously not the natural outlet of the present Val-Piora drainage: it is evidently either a 'stolen' outlet, due to some disturbance in

the original flow, or the relics of an earlier drainage before the present Val Piora came into existence, for it turns off at right angles to the general line of the valley. I think, however, that it flowed over its present exit previous to the formation of the lakes, and that their formation may be connected with the diversion of the drainage into the 'Foos' channel.

As the valley is entirely rock-bound, the diversion cannot be due to the blocking of an old outlet at the western end; it must, therefore, be due to the direct encroachment of the Foos on the Piora watershed, through which it has cut. This can only have happened if the Ticino Valley were more rapidly overdeepened than the valley into which the original Piora river drained. Obviously, therefore, it did not drain directly into the Ticino; but where else could it drain? There are only two answers to this question. One is, that it drained over the col between Fongio and Pian' Alto, at the western end of Ritom, into the Val Canaria, as suggested by Prof. Bonney; the other is, that it flowed eastwards, and not westwards, over what is now the Passo del Uomo, and that the drainage to the west of this pass has therefore been reversed. This latter explanation would account, not only for the hanging valley of La Foos, but also for those at the eastern end of Lago Ritom and below Lago Tom. It is probable, however, that there were several stages in this process, which appear to have been as follows:—

(1) Before the present depression of the Val Piora existed, the general drainage of the district would be very different from that of the present day, and a stream rising on the Camoghè range may perhaps have flowed eastwards into the Medelser Rhein in Pliocene times. About this, however, it is difficult to be certain, as no relic of that period remains.

(2) The overdeepening of the Ticino Valley, which then appears to have taken place, may have enabled a stream from the Val Canaria to cut back over what is now the Fongio col as far as the head of the present Tom Valley. This diversion, although unconnected with the formation of the lakes, appears to be indicated by the present depression between Fongio and Pian' Alto.

(3) This overdeepening by the Ticino, postulated above, would enable the Foos, which then rose on the northern slope of the Val Ticino, to cut back its head-waters until it captured the drainage of the present Tom Valley.

This would naturally result from the circumstance that, whereas the Foos drained directly into the overdeepened Ticino Valley, the stream over the Fongio col drained indirectly into that valley, through the Val Canaria, which, at that time, would not have yet adjusted itself to the Ticino level. Relics of the drainage as it existed at that time are clearly visible at the present day, not only in the Foos Valley draining northwards and southwards from the col between the Punta Nera and the Taneda to the Ticino, but also in the low watershed (not yet completely destroyed) running parallel with this valley from the Taneda, and now separating Lago Tom from Lago Cadagno.

(4) This watershed was next gradually cut through by an eastern tributary of La Foos at its weakest point, namely, the point occupied by the rauchwacke along the line of the present Lago Ritom, and this tributary extended farther and farther to the east, to form the present Val Piora. On this supposition, namely that the Foos Valley existed before the Val Piora, it is easy to account for the fact, otherwise difficult of explanation, that the present drainage from the Val Piora turns at right angles where it discharges itself into the Ticino Valley.

(5) An uplift of the range to the west, possibly connected with the melting-

off of the ice, caused a diminution in the flow of the drainage in this valley, and the solution of the rauchwacke gradually produced a hollow extending as far as the limits of this calcareous rock. Thus at the present day, as shown above, Lago Ritom is bounded on the north and north-east by steep walls of crystalline schist, while its southern margin is formed by the dip-slope of the underlying gneiss. The same cause may reasonably be assumed to have operated in the case of Lago Tom and also of Lago Cadagno.

In this survey of the physical history of the district, I have not included the formation of the two upper lakes situated near the watershed, namely Lago Scuro and Lago Taneda. These lakes are, indeed, difficult to account for on any hypothesis. One fact, however, appears certain, namely, that to whatever they owe their existence, their occurrence along the junction of two dissimilar rock-masses must have been the prime determining cause.

III. The Lago-Tremorgio Group.

This consists really of several groups of tarns scattered along both sides of the southern watershed of the Val Levantina. They lie for the most part along the outcrop of the calcareous schists, in some cases exactly along the junction of these rocks with the gneiss.

Lago Tremorgio.—I will take this as a type of the lakes of this group, as it is not only the largest, but, I think, the most interesting, and certainly the deepest, of those occupying the southern slopes of the Val Levantina. It is also one of the lakes enumerated by Prof. Bonney among true rock-basins. It lies at a height of 5996 feet above sea-level, and 2880 feet above the Ticino. It is nearly circular in shape, having a maximum diameter from north-east to south-west of 853 yards, and a width at right-angles to this of 787 yards.

The overflow escapes through a narrow waterworn notch at the north-eastern corner, the lower few feet of which appear, as Prof. Bonney remarks, to be artificial, and falls into the Ticino by a series of cascades; in winter, however, this stream is dry. With the exception of this channel, the lake is entirely surrounded by steep hillsides (see Pl. XIV, fig. 1). All round the southern shore the lake is bounded by precipitous rocks, the upper 500 feet forming an inaccessible cliff, the average slope from the water's edge being 55°. The slopes from the northern and western walls are gentler, but even these show an inclination of 30° to the point on the northern watershed which is marked 2047 m. in the Swiss Government map.

The lake therefore lies in a funnel-shaped rock-basin, the rim of which runs about 700 feet above the lake, except where it is broken through at the exit: the average slope of the sides of the funnel being about 45°. In fact, if we consider a funnel having this slope to be tilted towards the north-west, we get an exact representation of the shape of the basin. Prof. Bonney aptly compares it to an armchair, which it certainly resembles, only the arms curve round

in front till they nearly meet, so that it could only be sat in with the legs crossed. It is obvious that, in considering the origin of the lake, we must take into account the whole of this funnel before it was breached at the exit, as it is probable that the water of the lake once stood at a much higher level before the notch had been eroded and cut down to its present depth.

The basin does not lie in the path of any valley, for, with the exception of a small stream coming down a gully from Ponc. Tremorgio on the west, the only drainage that it receives pours over the southern rim of the funnel from the Campolungo Alp.

This stream originates in a small lake, apparently a rock-basin, lying high up at 7436 feet above the sea, north of the Campolungo peak. Local tradition has it that this lake is unfathomable, which probably means that it is more than 20 feet deep. The stream from this lake appears originally to have flowed over the Campolungo Pass westwards into the Val Maggia, and to have been afterwards diverted into the Lago-Tremorgio drainage, as the valley was carved out of the dolomite in which the Campolungo Alp lies. The lake cannot, therefore, by any possibility be regarded as occupying an overdeepened pre-Glacial valley, and it resembles nothing so much as a large swallow-hole.

The greatest depth of the lake is said to be 120 metres (394 feet) near the centre. I give this on the authority of Mr. Fraser, an engineer residing at Lugano, who took soundings from a raft. Unfortunately, my attempts to sound this lake were frustrated on two occasions; the first time by bad weather and fogs, and the second time, after partly completing the soundings, the line was so repeatedly cut by sharp submerged reefs that I was obliged to abandon the endeavour, the time at my disposal preventing a third attempt. The discovery of these reefs, however, is not without bearing on the origin of the lake. From the soundings which I obtained, the depth appears to increase very regularly from the western corner towards the centre; and if this general slope continues, it would give a depth of 250 feet at the centre of the lake. This is not the case, however, near the northern shore, which falls steeply from the outlet. The lake is excavated in the calcareous schists. The reefs running out from the south-western corner contain 'eyes' of massive andalusite with a hardness of $7\frac{1}{2}$.

The lime in the calcareous schist is chiefly present in the form of eyes of crystalline calcite, which measure frequently several inches across, and crumble at the touch; and, where portions of the rock were obtained from the edge of the lake, these eyes were frequently represented by holes, the calcite having been entirely or partly dissolved out.

The lake cannot be considered as the result of glacial erosion. The production of a funnel-shaped hollow 1000 feet deep, with an upward slope of 30° on the exit-side, cannot have been produced by ice-action; and the origin of the hollow in which the lake lies must, I think, be attributed to chemical solution. Two important facts seem to bear on this hypothesis: one is the way in which the

level of the lake sinks several metres below its outlet in winter, and the other is the occurrence of springs (issuing from the precipice below the lake) which continue to flow all the year round. This latter circumstance has been made use of by the engineers of the St. Gotthard Railway, who obtain the water for their locomotives, not from the overflow-torrent from the lake, but from these permanent springs. The solution of the calcareous portions of the schist might cause the funnel-shaped hollow in which the lake lies; but it is also possible that the dolomite which occupies the Campolungo Alp may have been folded in under the lake, as shown in the very suggestive section to the west of the Campolungo Pass (see Pl. XIII, fig. 2). If this fold be continued underground, it must certainly pass beneath the lake. The fact that the outcrop of the dolomite strikes across the schist, and terminates abruptly at either end against the gneiss, only to reappear as an isolated outcrop in the Val Piumogno on the east, is a very suggestive one, as it emphasizes once more the inconstancy of these eyes of dolomite and their fortuitous occurrence among the crystalline rocks.

Of the remaining lakes of this group, those scattered along the southern side of the Ticino watershed are the most important. They drain either directly into the Val Maggia, or indirectly through the Val Bavona. The Lago di Naret has a wedge of crystalline limestone running across it, while the Lago Sciundrau is situated on the junction of dolomite and gneiss. The Laghetti or lakelets to the east of Lago di Naret, again, lie along the junction of the calcareous schist and the gneiss; their origin would appear, therefore, to be similar to that of the lakes of the Val Piora. But, without soundings and detailed investigation, it is best to leave their origin an open question for the present, as they will well repay further investigation.

IV. The St. Gotthard Lakes. (For topographical map, see p. 186.)

At the northern end of the Canton lie a small group of lakes near the summit of the St. Gotthard Pass. Of these, the Lago della Sella and the Hospice-tarns drain southwards by the Val Tremola to the Ticino, while the Lago di Lucendro, the Lago Orsirora, and the Lago Orsino supply the headwaters of the infant Reuss.

The Hospice-lakes are small rock-pools, which owe their existence partly to artificial means, having been in some cases dammed by the old monks of the Hospice to serve as fishponds, which still yield fine trout. They are also partly due to the highroad embankment thrown across the swampy summit of the pass. The portion of the largest lake north of the road is only about 16 feet deep; the southern portion appears to be deeper, but I should think cannot exceed 50 feet in depth.[1] Of the others, the Lago di Lucendro is by far the most important.

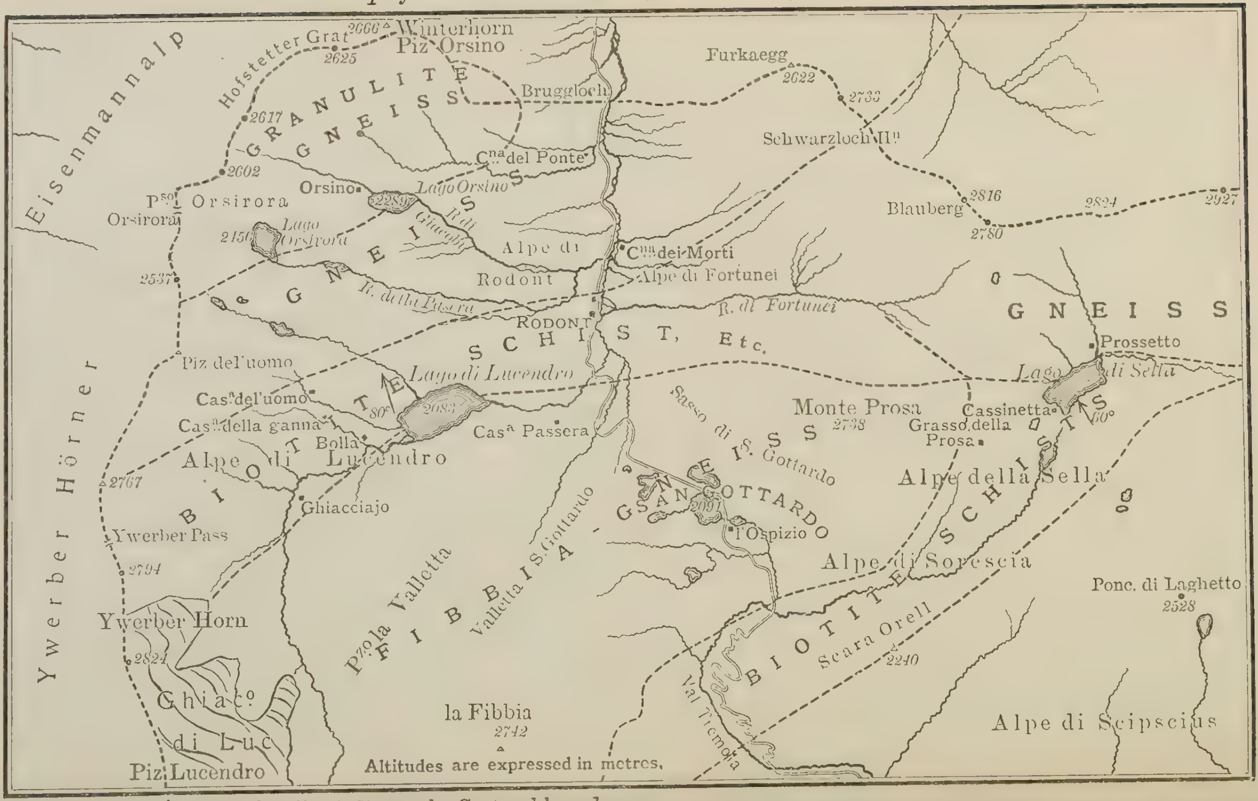
[1] The deepest sounding met with.

Lago di Lucendro (see Pls. XIV, XV, & XXI).—This lake lies at a height of 6832 feet above sea-level, in the valley between the Piz Lucendro and the valley of the Gotthard Reuss, above Hospenthal. In shape, it is roughly a parallelogram, with the longer diameter running north-east and south-west. The greatest length from east to west is rather more than 765 yards; and the greatest width is 306 yards, the average width being about 270 yards. The water is, to a slight extent, retained by the supports of the bridge at the exit. The greatest depth met with was 126 feet; and the axis of greatest depth, as shown in the bathymetrical chart (Pl. XXI), lies parallel to the length of the lake, and rather nearer the western than the eastern bank. The prolongation of the contours along this line, into the bay at the western end, is an interesting feature of the chart. The valley in which the lake occurs is occupied at its upper end by the Lucendro Glacier. The drainage of this glacier is carried off by three streams, which form the source of the Reuss and constitute the chief feeders of the lake. This also receives the overflow from the little lake to the north-west, situated at the eastern base of the Piz del Uomo, and several streams which drain the cirque-like wall on the south and west of the lake. The lake occupies a rock-basin, and lies along the junction of the Fibbia gneiss and the biotite-schist, the latter occupying the northern bank. A good section of the schist is seen along the north side of the lake, about 500 yards from the bridge. Here the schist is much crushed and contorted, and penetrated by veins of granite. If the veins are offshoots of the Fibbia gneiss, the lake must lie absolutely along the junction of the two rocks: as in most other cases, however, the actual shore-line is modified by scree and delta-material.

With regard to the origin of this lake, there is no evidence of solution having played any part in its formation. On the other hand, the promontory of solid rock jutting out into the lake from the exit does not seem consistent with excavation by ice, as usually understood; and the presence of this lake along the junction of a massive granitic gneiss and a mica-schist points undoubtedly to the conclusion that here again the main determining factor for the existence of the lake has been the occurrence of a line of weakness along the contact between a hard and a comparatively-soft rock, giving rise to differential weathering. The whole district, however, has been intensely glaciated, and a prolongation of the Lucendro Glacier must formerly have passed over the site of the lake. It is quite possible that this glacier removed the weathered surface of the disintegrated schist, while it made but slight impression on the harder granite. The uneven surface thus produced would cause the accumulation of water, so soon as the glacier withdrew from the lower part of the valley.

The origin of Lago Orsirora and Lago Orsino, on the north of Lago di Lucendro, appears to be due to the same cause, as they lie along the junction of the gneiss on the south and the granulite on

Map of the St. Gotthard lakes, on the scale of 1 : 50,000.



This broken line indicates the Cantonal boundary.

the north, while the smaller tarns are obviously dammed by loose material.

Lago della Sella.—This lake forms an irregular sheet of water lying in the Val Torta, east of Monte Prosa, at a height of 7320 feet. It consists of a shallow lake on the north and a smaller pond on the south, united by a rocky ditch about 180 yards long,—the whole giving the idea of a flooded river-system (see Pl. XV, fig. 2). The actual exit is dammed by a landslip, although the lower sheet is certainly a rock-basin. The northern and western shores of the main lake are formed of gneiss, while biotite-schist occupies the southern and eastern banks. This schist resembles that which forms the northern bank of Lago di Lucendro, and is penetrated by similar granite-veins.

The strike of the schist is north-east and south-west, parallel with the longer axis of the lake, the dip being some 60° north-westward. The schist forms a rocky ridge running into the southern end of the lake. This rises to the surface again in two islands, united under water by shallow depressions only 12 feet deep. Five rows of soundings were run across various portions of the lake, but the presence of the islands made a systematic survey difficult in the absence of a boat. The greatest depth met with was 25 feet, though it is possible that greater depths may exist near the upper end of the lake. The origin of the lake, however, seems to be due to precisely the same causes as Lago di Lucendro, namely, a line of junction between gneiss and biotite-schist along which unequal weathering has taken place, the more weathered portions having been removed by the ice, which must once have gathered in the Val Torta and flowed over the district now occupied by the lake. It is noteworthy, in this connection, that the stream now flowing into the lake from the Val Torta runs for over a mile exactly along the junction of the gneiss and the schist.

V. The Lago d'Elio.[1]

Although situated just beyond the political boundary, this lake belongs geographically to the Ticino basin. It lies at a height of 3025 feet, or 2378 feet above the Lago Maggiore, and is situated on the watershed between the Val Molino and the Val Vedasco. It occupies an elongated triangular depression in the gneiss between Monte Borgna and Monte Cadrigna. The lake has a length of 930 yards from north-north-east to south-south-west, and a width at the upper end of 300 yards, which forms the base of the triangle: from here it gradually tapers to the exit, which lies in the acute angle of the triangle at its southern end. The deepest soundings were met with about one-third of the distance from the upper end, the greatest depth being 134 feet, while depths of 74 and 75 feet were

[1] A bathymetrical chart of this lake has been constructed; but it is unnecessary to introduce it here, as the lake has not been proved to be a rock-basin.

determined near the northern shore. The lake is, therefore, deepest towards its upper end, and shallows gradually to the exit. The northern shore is chiefly composed of loose material and boggy swamp, through which rise here and there hummocks of solid rock. The shape of the lake and the subaqueous contours, as well as the presence of loose material at the upper end, point to damming of a tributary valley by a landslip or moraine, and the reversal of the drainage over a gap in the watershed at its upper end. This view is borne out by the character of the exit, and also by the presence of a deep valley just beyond the accumulation at the northern end of the lake, into which it would apparently drain if the loose material were removed. There is, however, just a possibility that the lake may be to some extent rock-dammed.

VI. General Conclusions.

The results arrived at by a detailed investigation of the tarns in the northern portion of the Canton Ticino may, then, be summarized as follows.

The lakes can, for convenience, be grouped under two heads:—

(I) Those (*a*) entirely, or (*b*) partly dammed by loose material.

(*a*) Lago Camoghè.	(*b*) Lago di Murinascio.
„ Lisera.	„ Lucomagno.
„ Pettano.	„ Orsirora.
„ d'Elio.	„ Orsino.
	St. Gotthard tarns.

(II) True rock-basins due to (*c*) solution, (*d*) differential weathering.

(*c*) Lago Ritom.	(*d*) Lago Scuro.
„ Tom.	„ Taneda.
„ Cadagno.	„ di Lucendro.
„ Tremorgio.	„ della Sella.

Those grouped under I (*a*) require no comment. Those under I (*b*), in so far as they are rock-basins, may possibly be due to differential weathering, either by frost or by ice. It is, however, difficult to ascertain what depth, if any, we are to consider as rock-basins in each case, but it cannot be a very great depth. Lago di Murinascio and Lago Lucomagno lie upon ledges dipping steeply into the scarp-face at the foot of precipitous cliffs, above which there is no possible gathering-ground for a glacier, unless the ice poured over the cliffs in each case from the north; but the cliffs are too steep for it to arrive, even then, in anything but a fragmentary state. Consequently, even Prof. Bonney's general concession, that the ice, as it descended from the ranges above,

> 'would impinge on the level floor, on which under these circumstances it might have some erosive force,' (Geol. Mag. 1898, p. 19.)

does not seem applicable here, as the corries would be filled with snow and protected from any bombardment of this nature. It is, of course, always possible that the slight irregular erosion of a few feet might have been produced by the ice collected in the cirque, as

assumed by some authors to account for the formation of corrie-lakes in general; but it is difficult to realize the mechanics of the process, unless the ice found in these corries behaves rather differently from that of a glacier, and moves as a solid mass and not differentially as in a glacier. The lakes under notice are, however, comparatively unimportant; but, if any part of their basin is truly rockbound, they are difficult to account for, as they occur entirely in one rock-formation.

Rock-Basins.

II (*c*).—The chief lakes of the Val Piora are shown to lie along the junction of soluble calcareous rocks with gneiss or schists. Detailed soundings prove that the axes of greatest depth of these lakes coincide very closely with these lines of junction. Although the district must have been below the snow-line in Glacial times, there is very little sign of glacial action visible at the present day, and it is difficult to understand how ice can have taken any real part in the formation of the lakes.

Chemical evidence derived from analyses of the rauchwacke and from the composition of the water of the lakes, points strongly to solution having played a conspicuous part in the formation of these lakes. This is confirmed by the fact that, in the case of Lago Tom, the surplus-water does not overflow the containing barrier of rauchwacke at the exit-end, but, percolating into the heart of the limestone, reappears as a spring which rises exactly at the junction of the rauchwacke with the underlying schist.

Other evidence, such as the high percentage of dolomite-grains in the fine deposit forming the floor of the lake near the exit, evidently representing the less soluble portion of the rauchwacke, points in the same direction. In the case of Lago Ritom, it is shown that the whole of the western end of the lake is occupied by rauchwacke, although not so shown on the Swiss Geological Survey-map, and that the lake may be considered to occupy the site of a lenticular thickening of the calcareous beds similar to those which occur west and east of it along the same general strike. The marked increase in the amount of dissolved salts in the bottom-water of this lake, coupled with an equally-marked rise in temperature, are facts which point strongly to underground solution in the form of subaqueous springs; while the high percentage of sulphuric acid can only be explained on the supposition that beds of gypsum occur under this basin, similar to those found along the outcrop on the west and east.

Lago Tremorgio appears, from its characteristic pothole shape, to be also due to solution. It is situated on calcareous mica-schist, and the eyes of calcite in the schist are dissolved out from the rocks bordering the edge of the lake. It is also possible that the fold of dolomite, visible in the Campolungo Pass above the lake, may continue downwards to the lake-floor; and, if this should be the case, it would amply account for the basin by solution. The fall of the

surface of the lake several feet below the exit in winter, and the continuous flow of springs which issue all the year round from the hillside below the lake, point also to solution as the probable origin of this lake. It does not appear to be possible to attribute this lake to glacial excavation, as it does not form part of a valley-system which could have been overdeepened by ice to produce the present basin.

II (*d*).—There remain four important rock-basins which are more difficult to explain. They resemble the foregoing group in the fact that they all lie along the junction of two different rock-types, so that, whatever the weathering agent may have been which finally produced the basin, the occurrence of the lakes in their present position seems certainly here again to have been determined by structural lines of weakness. Lago di Lucendro lies in the track of an extension of the Lucendro Glacier, and Lago della Sella also occupies a valley at the head of which a glacier-system still exists. It is possible, therefore, that differential weathering in pre-Glacial or inter-Glacial times, along the junction between the gneiss and the biotite-schist, may have caused an unequal removal of material by ice in Glacial times. This excavation does not appear to have been so much in the nature of digging, as of the removal of less resistant, possibly more weathered, material. This is shown by the marked convexity of the outlines of the gneiss even under water, by the presence of the rocky headland at the exit of Lago di Lucendro, and also by the occurrence of the islands of solid rock running through Lago della Sella. The two remaining lakes of this group, namely Lago Scuro and Lago Taneda, which occur within a stone's throw of the main watershed and occupy basins 140 feet deep, are certainly very puzzling: for, although they lie along the junction of schist and gneiss, the theory of solution does not appear to be applicable here. Had these lakes lain in glaciated valleys, they would have undoubtedly been considered by many geologists as typical ice-excavated basins. Their occurrence, however, a few metres below the watershed, as well as the presence of submerged reefs running round the southern end of Lago Scuro, seems to preclude the possibility of excavation by ice.

The lakes, then, of the Canton Ticino that have so far been examined, with the possible exception of the rock-pools of the St. Gotthard Hospice, do not seem to be due to ice-erosion in the generally-understood sense, if we adopt the most recent definition by Prof. James Geikie for this class of lake, as contained in the following statement:[1]

'Rock-basins of glacial origin differ from all others in the fact that they are totally independent of geological structure and the character of the rocks themselves.'

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[1] 'Structural & Field-Geology' 1905, p. 416.

EXPLANATION OF PLATES VII–XXI.

Plate VII (facing p. 168).

Map of the Piora Lakes, on the scale of 1 : 42,240.

Plate VIII.

View of Lago Ritom, looking east from the exit of the lake. It shows the contrast between the dip-slope of the gneiss on the southern shore, with its bays and headlands, and the escarpment of calc-mica and black-garnet schists forming the northern shore, down which cascade the three waterfalls from Lago Tom, Lago Cadagno, and the Val Piora respectively, counting from left to right, and terminating at the edge of the lake in their respective deltas. Pizzo Taneda forms the highest point along the skyline; while immediately to the left lies the col over to Lago Scuro, from which the photograph (reproduced in Pl. X) was taken. Below this, again, the notch in the middle distance marks a portion of the old Foos valley. On the skyline to the right of Pizzo Taneda is seen the gap occupied by Lago Taneda, the overflow from which can be discerned falling over the precipice of actinolite-schist into the Lago Cadagno, which lies immediately below. The Val Piora is situated on the extreme right of the photograph, behind the middle-distance escarpment, while Lago di Murinascio occupies the cirque above it.

Plate IX.

View of Lago Tom, looking towards the barrier of rauchwacke at the lower end, in which the water-channel leading into the rock is seen. The delta on the extreme right forms the upper end of the lake. The rauchwacke is seen occupying the centre of the picture. The skyline is composed of dip-slopes and escarpments, on the right and left respectively of each of the hills.

Plate X.

View taken from the col to the west of Pizzo Taneda (shown in Pl. VIII), looking across Lago Tom and the western end of Lago Ritom to the Val Levantina. The observer is looking straight down the old valley of La Foos, sections of which can still be seen below Lago Tom and at the exit of Lago Ritom. The distant range forms the watershed between the Val Levantina and the Val Maggia, and, although not visible, Lago Tremorgio lies on the flank of this range on the extreme left. The snow-filled lake in the foreground is scree-dammed, and lies on a ledge of actinolite-garnet-schist 1000 feet above Lago Tom.

Plate XI.

Panoramic view from the watershed between Lago Tom and Lago Cadagno, looking east. Lago Cadagno lies in the foreground on the left, and the gap immediately above it is occupied by Lago di Murinascio; while the delta at the head of Lago Ritom lies below on the right. The stream running into this down the wooded slope marks the isolated outcrop of rauchwacke at the eastern end of the lake. Up the centre of the picture runs the Val Piora, cut in the outcrop of the main mass of rauchwacke. Starting in the Pizzo Columbe (which forms the central peak in the skyline), this runs through Lago Cadagno, through the point from which the photograph was taken to Lago Tom, and away to the Val Canaria. The cattle-sheds in the foreground are built on the screes which dam the western end of the lake; while behind them, the moraine is seen forming its southern shore. The dip-slopes and scarp-faces formed by the actinolite-schists are well seen on the left in the middle distance; while the gorges, through which the rivers from Lago Cadagno and the Val Piora fall into the Lago-Ritom basin, are conspicuous in the foreground.

Plate XII.

Fig. 1 is a view of the barrier of rauchwacke at the lower end of Lago Tom. It shows the spring issuing from the rauchwacke at its junction with the

underlying schist, which lies just beyond the photograph to the right. The cave from which the spring formerly issued is seen in the distance; while the honeycombed appearance of the weathered rock is well shown.

Fig. 2 is a photograph taken from the col looking down on to Lago Scuro. It shows the circular shape of the outcrop and the reefs of rock separating the lake into two portions, one of which is seen in shadow in the right-hand bottom corner. The exit of the lake, where it overflows into the Val Cadlimo, lies on the far side of the lake, on the extreme left.

Plate XIII.

Fig. 1 is a view of the western end of Lago Ritom; the exit is masked by one of the promontories of gneiss on the left of the picture. The wooded slope behind the hotel is the 1930-metre hill. The lower portion, on which the hotel stands, is formed of gneiss; but the upper slopes, above and to the right of the house, are formed of the dolomite which sweeps round the end of the lake, also rising to form the col over the hill to the left and up to a line half way between the lake and the highest point—Fongio.

Fig. 2 shows the fold of dolomite in the Campolungo Pass. The dolomite strikes towards the observer on the left, dipping south-eastwards at a high angle. The mass of dolomite occupying the centre of the picture has been folded and faulted down to the right of the main outcrop, and it is possible that it is continued under Lago Tremorgio, which lies immediately below, just outside the right-hand corner of the picture.

The flat little valley is evidently eroded out of the dolomite; the stream flowing along it comes from the lake high up on the left, and appears to have been a somewhat recent diversion.

Plate XIV.

Fig. 1 is a photograph of the lower end of Lago Tremorgio, showing the steep high cliffs surrounding the lake and the notch cut down at the exit. These cliffs continue all round the rest of the lake, becoming nearly vertical opposite the exit; and it is over this cliff that the stream, shown in fig. 2 of Pl. XIII, falls into the lake. The outcrop of the dolomite lies at the top of this cliff, to the right, outside the photograph.

Fig. 2 shows the Lago di Lucendro, seen from the upper end. On the right is the Fibbia gneiss, on the left the biotite-schist, the junction running down the centre of the lake. The bare convex surface of the glaciated gneiss at the lower end of the lake is well seen. The river in the foreground rises in the Lucendro Glacier, and forms the source of the Reuss.

Plate XV.

Fig. 1 is another view of the Lago di Lucendro, taken from high up on the left bank. It shows the tongue of solid rock running back into the lake from the exit, mentioned in the text (pp. 185 & 190), and also the glaciated Fibbia gneiss near the exit. The dark rock in the lower part of the foreground is the outcrop of the contorted biotite-schist penetrated by granite-veins. In the distance is seen the St. Gotthard road, and beyond it the Hospice-lakes.

Fig. 2 is a view of the Lago della Sella seen from near the exit, showing the islands and illustrating its river-like character. The immediate foreground and the right bank are formed of biotite-schist, penetrated in places below the exit by veins of granite, where it borders on the Fibbia gneiss; while the greater part of the left bank is composed of gneiss. (See also map, p. 186.)

Plate XVI.

Contoured map of Lago Ritom, on the scale of 20,000 : 3. *For* 'Airola' *read* 'Airolo.'

Plate XVII.

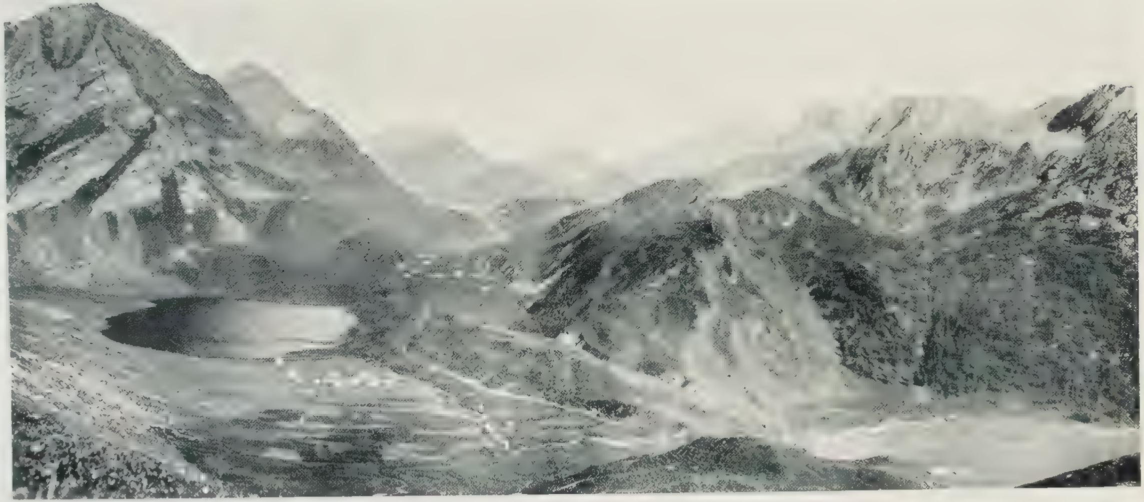
Contoured map of Lago Tom, on the scale of 5000 : 1.

E. J. G., *Photo.*

LAGO RITOM SEEN FROM THE WEST.

E. J. G., Photo.

LAGO TOM. VIEWED FROM THE NORTH-EAST.



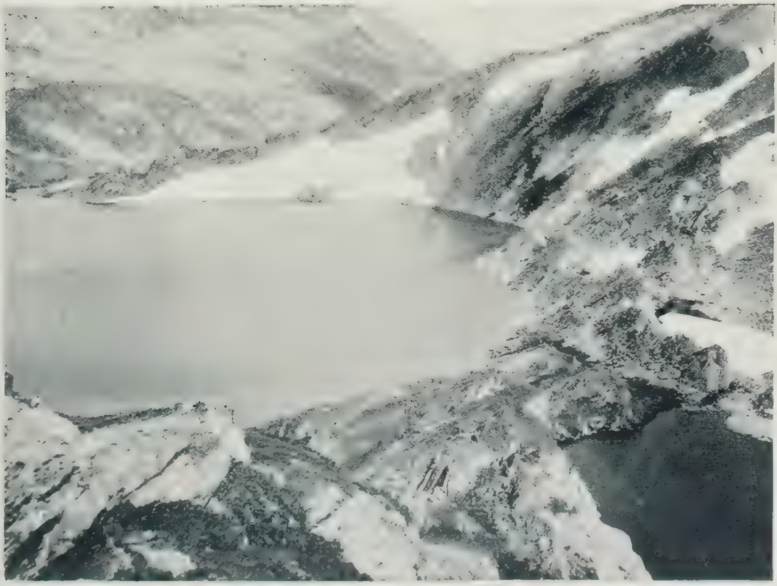
THE VAL PIORA AND LAGO CADAGNO, SEEN FROM ABOVE LAGO TOM.

FIG. 1.

E. J. G., Photo

SPRING ISSUING FROM THE RAUCHWACKE, BELOW LAGO TOM.

FIG. 2.



E. J. G., Photo

LAGO SCURO, LOOKING NORTH FROM THE WATERSHED.

Fig. 1.

E. J. G. photo.

THE WESTERN END OF LAGO RITOM.

Fig. 2.

E. J. G. photo.

FOLD IN THE DOLOMITE, SOUTH OF LAGO TREMORGIO.

Fig. 1.

E. J. G., Photo.

THE EXIT OF LAGO TREMORGIO, SEEN FROM THE SOUTH-WEST

Fig. 2

E. J. G., Photo.

LAGO LUCENDRO, SEEN FROM THE SOUTH.

FIG. 1.

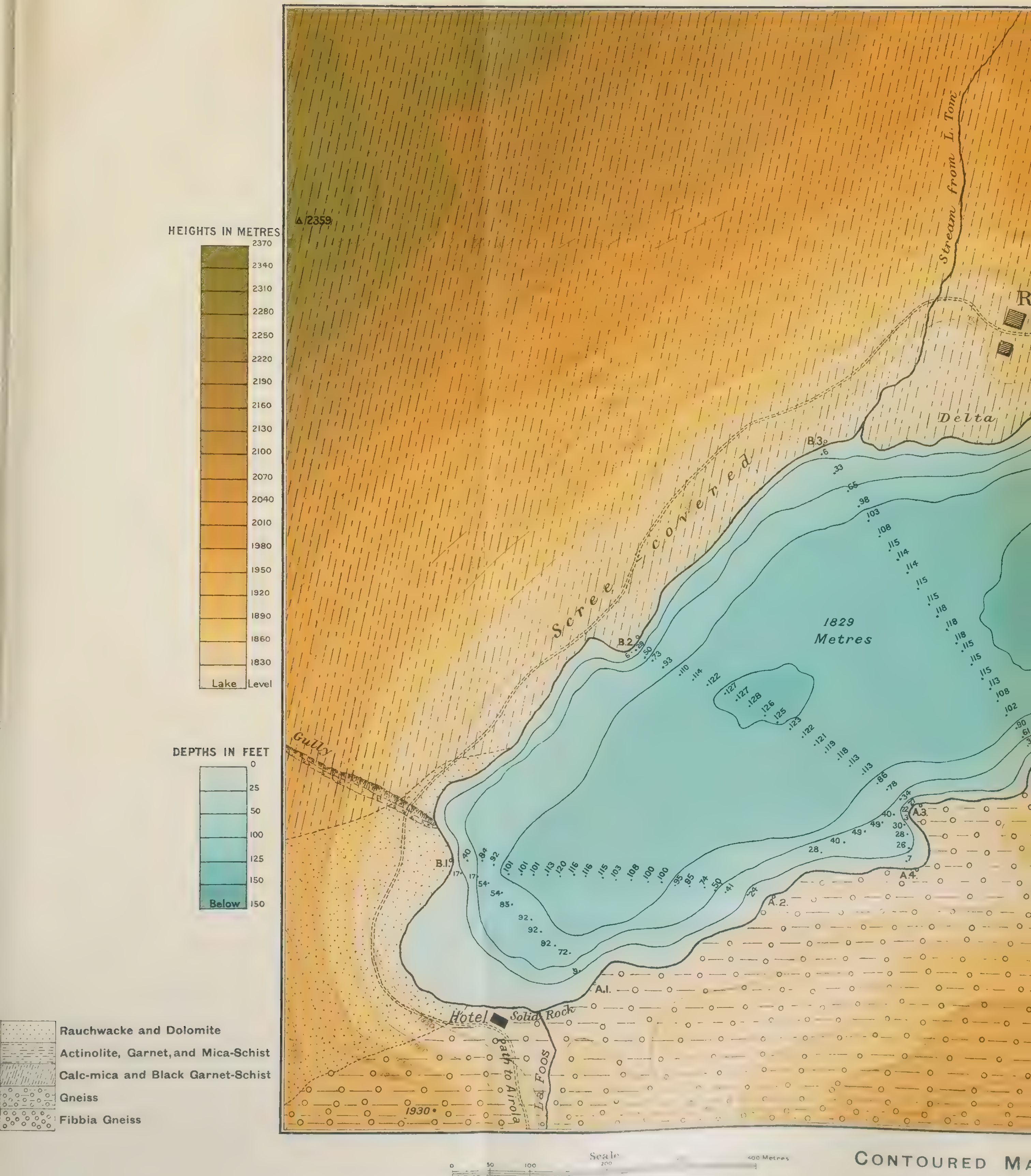
E.J.G., Photo.

VIEW OF LAGO LUCENDRO, SHOWING THE EXIT.

FIG. 2

E.J.G., Photo.

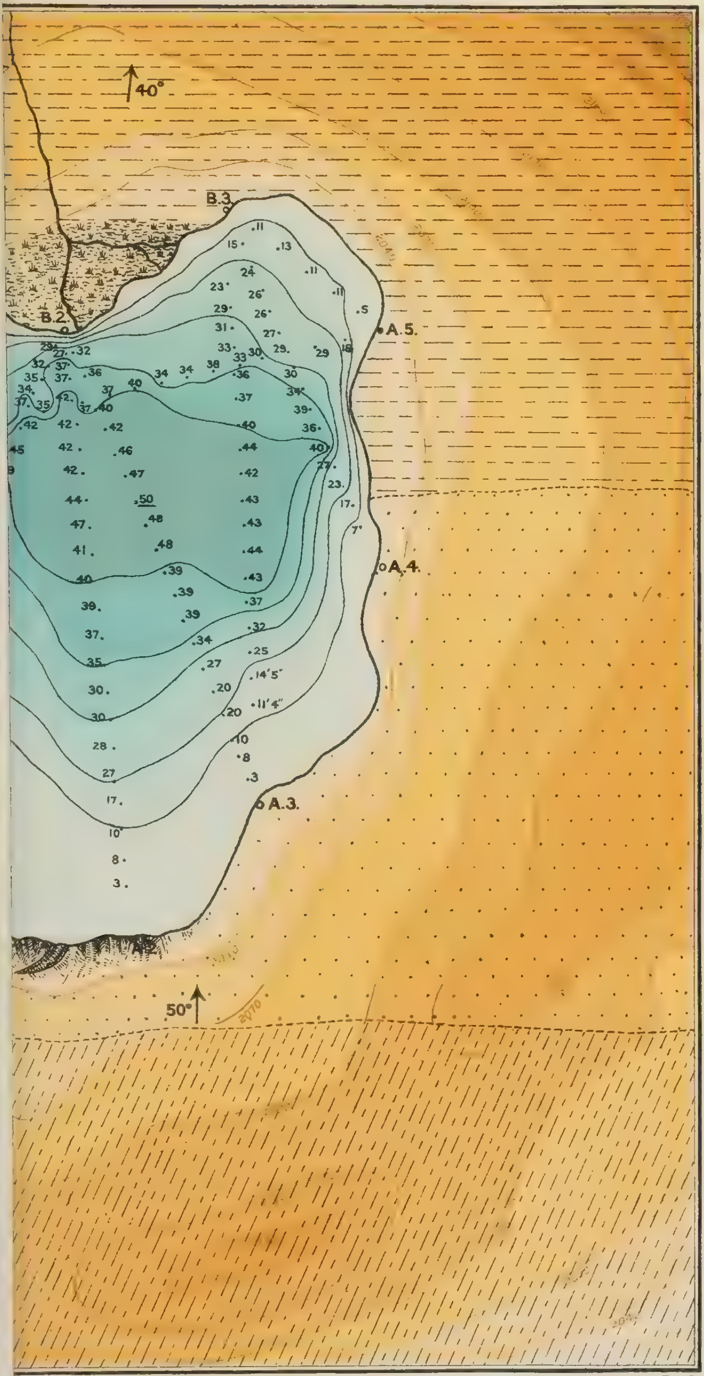
LAGO DELLA SELLA, SEEN FROM THE SOUTH-WEST.



CONTOURED MA

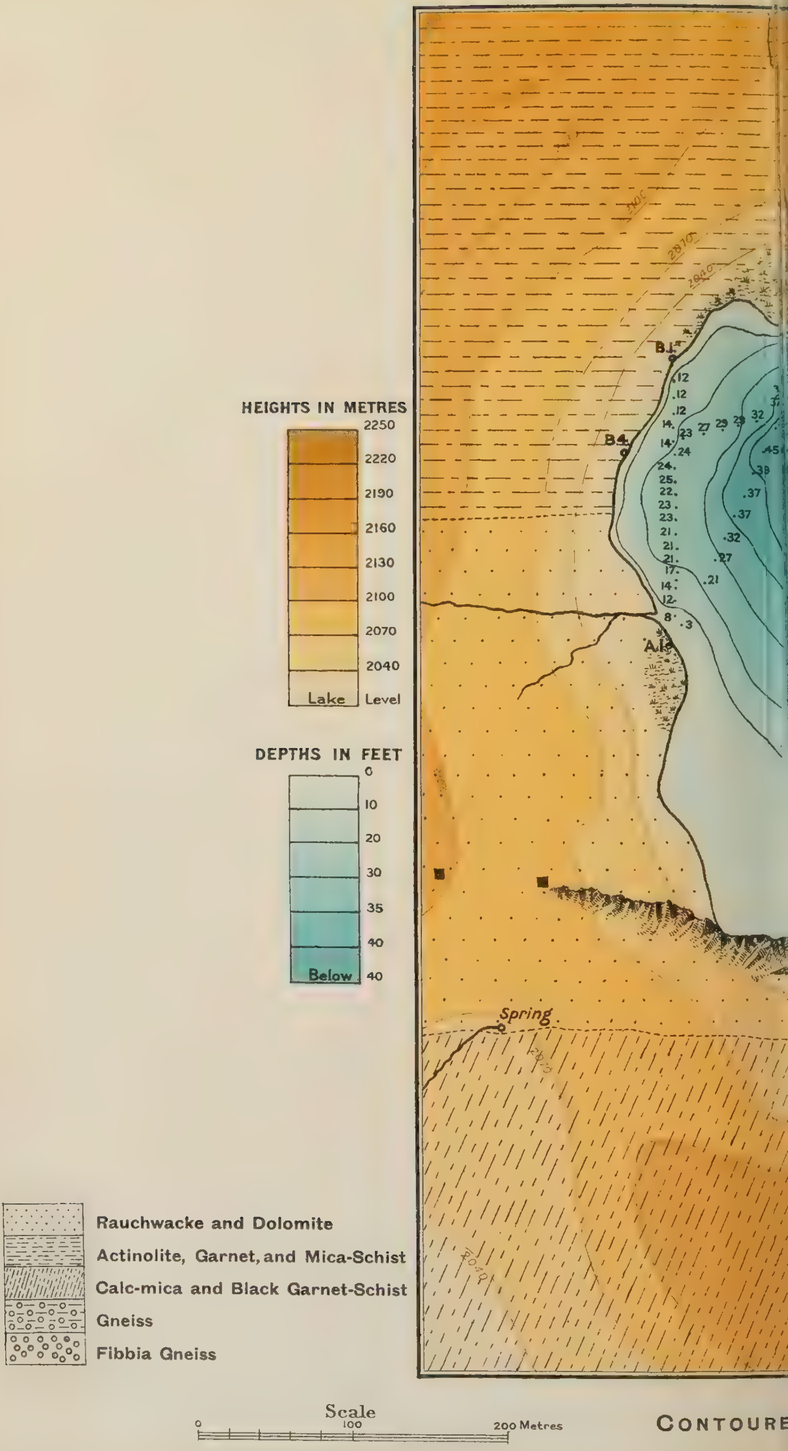
Bartholomew, Litho, Edin.

P OF LAGO RITOM (1829 M.)

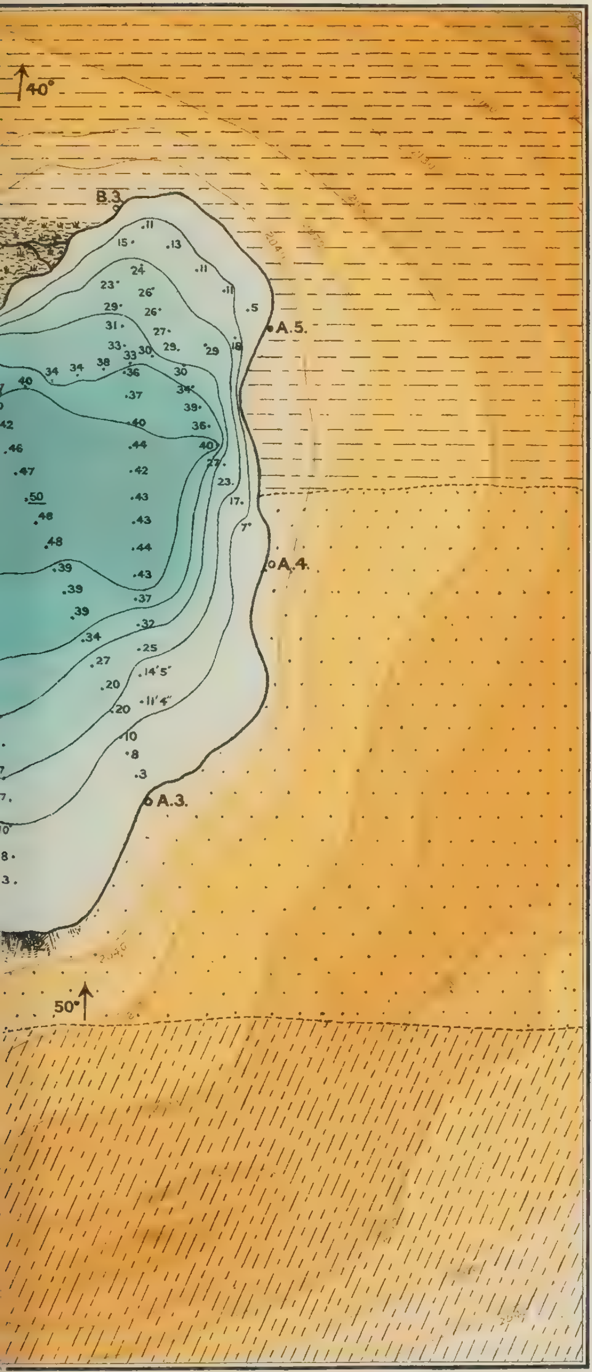


Bartholomew, Litho, Edin[r]

ED MAP OF LAGO TOM (2023 M.)

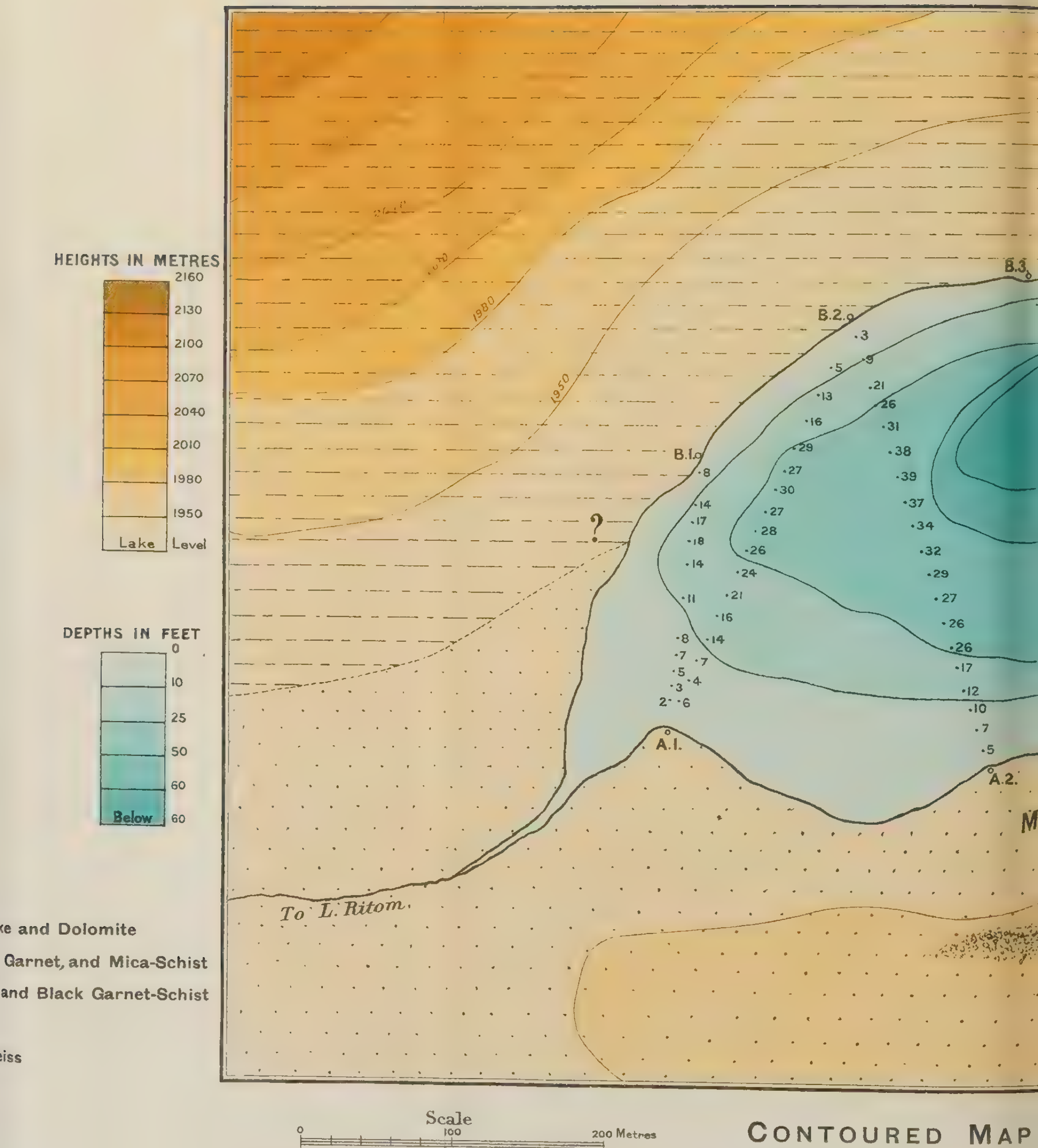

HEIGHTS IN METRES
2250
2220
2190
2160
2130
2100
2070
2040
Lake Level
DEPTHS IN FEET
0
10
20
30
35
40
Below 40
Rauchwacke and Dolomite
Actinolite, Garnet, and Mica-Schist
Calc-mica and Black Garnet-Schist
Gneiss
Fibbia Gneiss
B.1.
B.4.
A.1.
Spring
2100
2070
2040
Scale
0
100
200 Metres

CONTOURE

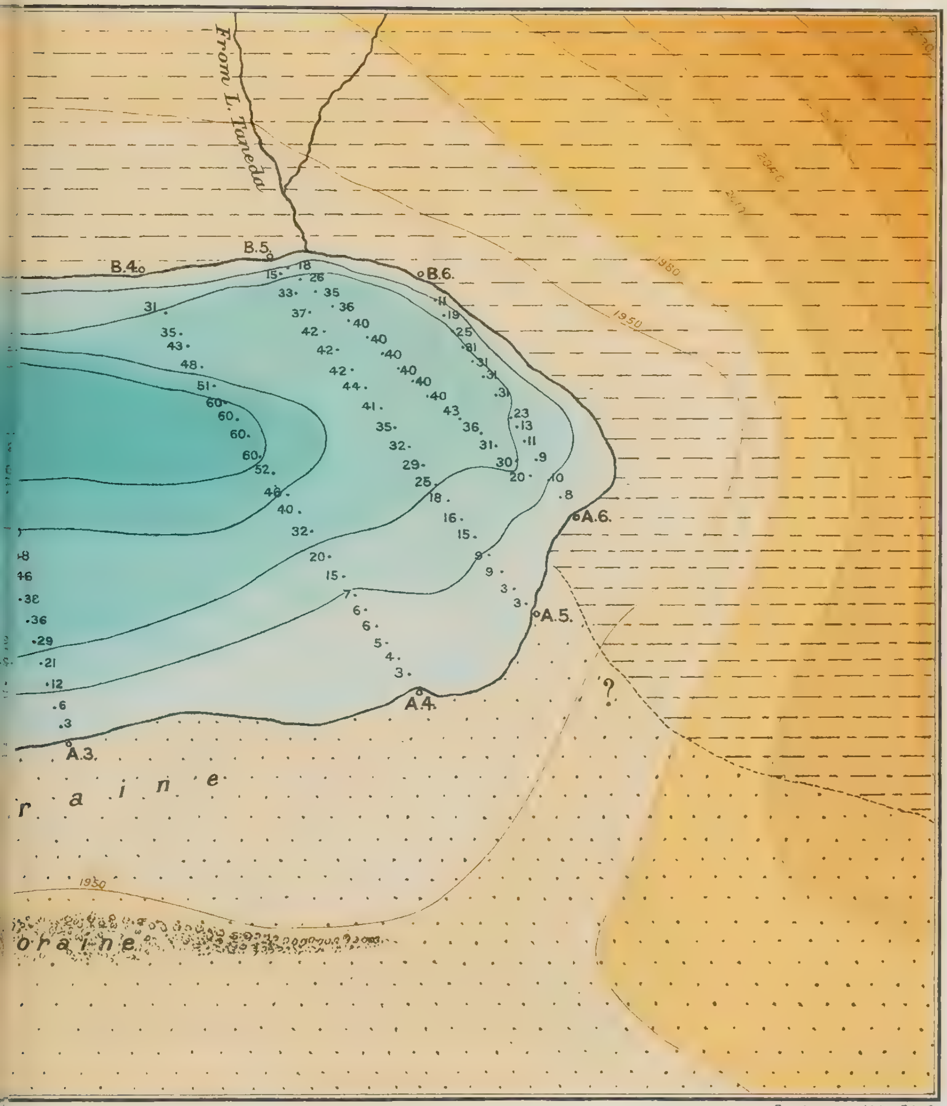


Bartholomew, Litho, Edinr.

… OF LAGO TOM (2023 M.)

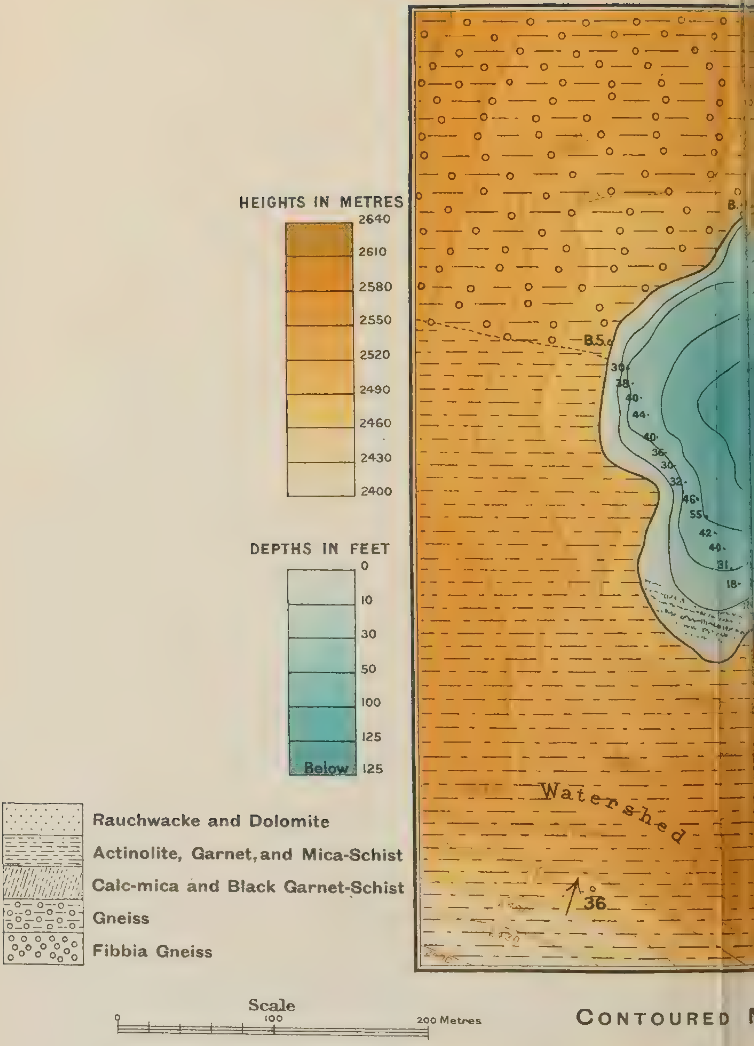


CONTOURED MAP

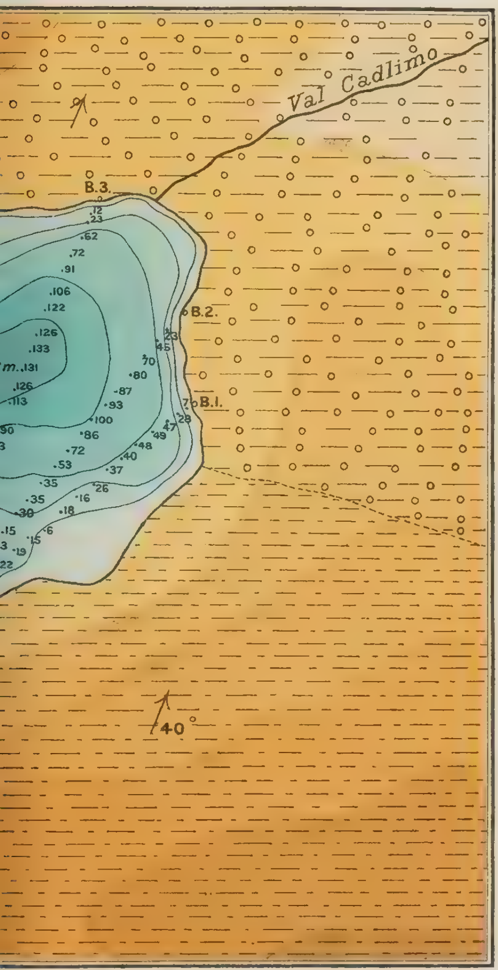


Bartholomew, Litho, Edin.

LAGO CADAGNO (1921 M.)


HEIGHTS IN METRES
2640
2610
2580
2550
2520
2490
2460
2430
2400
DEPTHS IN FEET
0
10
30
50
100
125
Below 125
Rauchwacke and Dolomite
Actinolite, Garnet, and Mica-Schist
Calc-mica and Black Garnet-Schist
Gneiss
Fibbia Gneiss
Scale
0
100
200 Metres
B.
B.5
30
38
40
44
40
36
30
32
46
55
42
40
31
18
Watershed
36

CONTOURED M

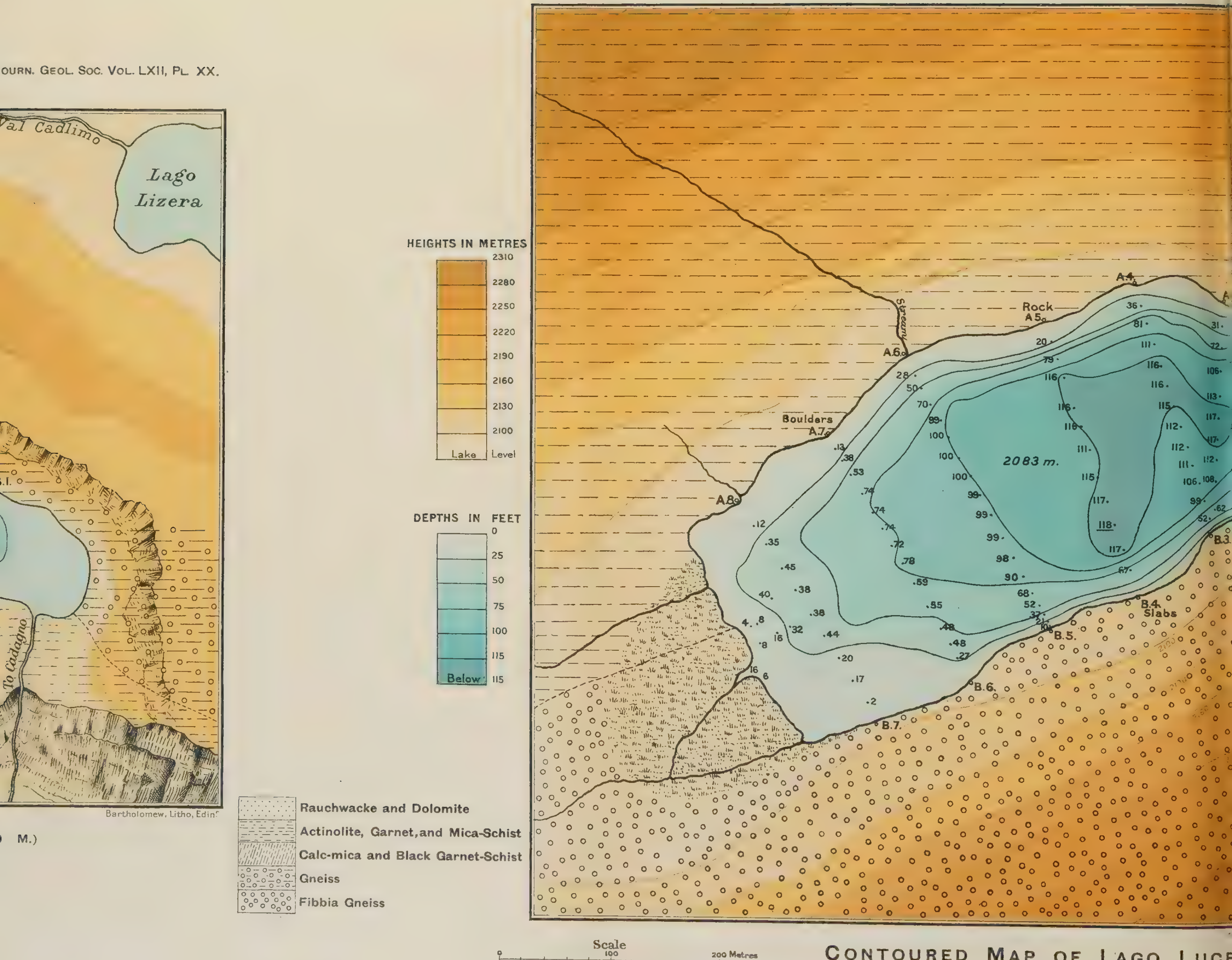


Bartholomew, Litho, Edin^r

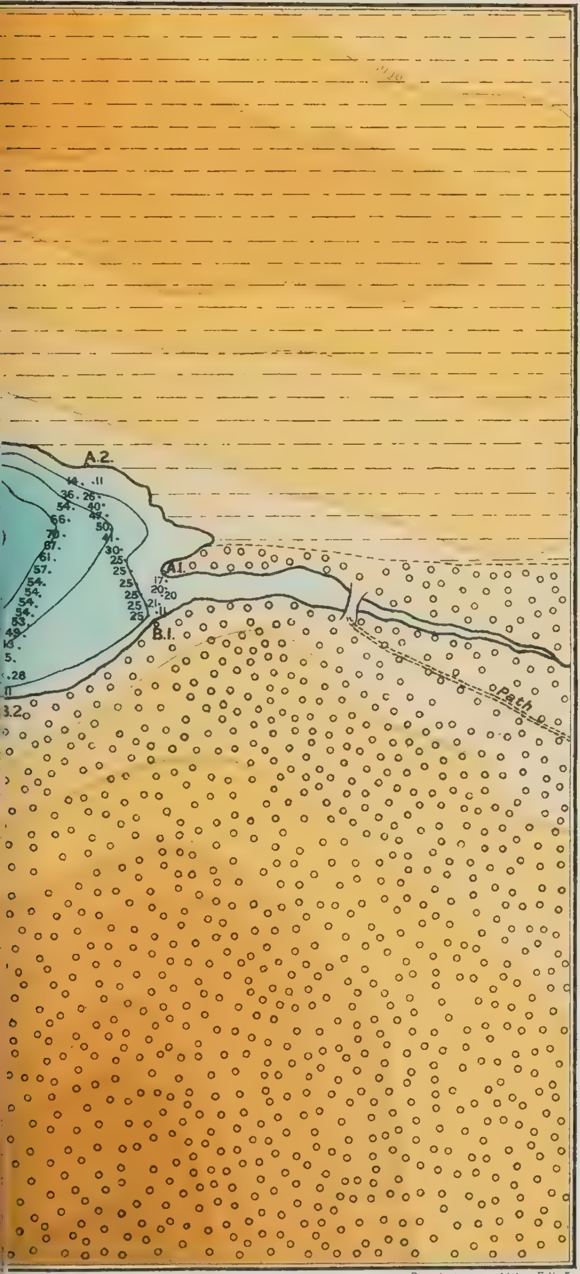
F LAGO SCURO (2453 M.)

CONTOURED MAP OF LAGO TANEDA (235

CONTOURED MAP OF LAGO TANEDA (235



CONTOURED MAP OF LAGO LUCE



Bartholomew, Litho, Edin.r

(2083 M.)

PLATE XVIII.

Contoured map of Lago Cadagno, on the scale of 5000 : 1.

PLATE XIX.

Contoured map of Lago Scuro, on the scale of 5000 : 1.

PLATE XX.

Contoured map of Lago Taneda, on the scale of 5000 : 1. *For* 'Lizera' *read* 'Lisera.'

PLATE XXI.

Contoured map of Lago di Lucendro, on the scale of 5000 : 1.

DISCUSSION.

The PRESIDENT observed that he would have liked to say much which, on account of the lateness of the hour, he must omit. He thought that the case of the deep lakelet Scuro and its companion, situated close below the watershed, was a hard nut for advocates of glacial erosion of such lakes to crack. He could not sit down without referring to the amount of labour devoted by the Author, not only to the study of the lakes, but also to the preparation of his paper for presentation to the Society.

Prof. BONNEY heartily concurred with the President's remarks on the thoroughness with which the Author had worked out his subject and the clearness of his exposition. He should like to state, for the information of the Fellows, that, in those lakes which he had described in the 'Geological Magazine,' he had not admitted that ice could have done more than form the rock-basin now filled with water. He had supposed, for instance, at the Lago di Tremorgio, that first a corrie was formed in the usual way by streams, and then, when the ice advanced, the descending mass might have a scooping effect, at the foot of so deep a slope. In regard to Lake Ritom, he felt doubts as to whether the headlands on the south side could be due to flexures, for these would correspond with the north-north-east to south-south-west folding, which he thought was on a large scale and was older than the east-to-west folding; he doubted also whether the nipped-up east-to-west strips of rauchwacke were sufficiently large to cause, when dissolved, so complete a removal of the intervening wedges of much less soluble rock. The idea of reversal in the Piora-Valley drainage presented difficulties to him. If the water escaped eastward (supposing the floor to be nearly at its present level), it would have to go over a pass now at least 1200 feet above the lake. He thought also that the deepening of the main valleys, to which the 'hanging valleys' were due, had been pre-Glacial, and that probably this part of the Val Bedretto would have been under ice, even in inter-Glacial times. But, while reserving judgment on these points until he had read the paper, he was none the less sensible of its value.

Dr. JOHNSTON-LAVIS asked the Author whether he had seen any signs of carbonic-acid springs in the sites of these curious lakes.

It struck him as curious that the soluble rocks should be dissolved only at some spots, and not at others where the active movement of streams would make one expect solution to be more rapid. Such irregularity pointed to some additional local agency, such as gas-laden springs, in determining the site of some of these lakes. Their occurrence also at the junction of different rocks would be partly explained by the crushing produced in earth-movement by differential shearing at such junctions. He quite agreed that glacier-action did not explain their origin. He would also remark that the minerals of the mica-group were much more soluble in a solution of carbon-dioxide than was usually supposed.

The Author thanked the President and Prof. Bonney for their kind remarks. In reply to the latter, he said that he thought the division on Dr. K. von Fritsch's map, between the rauchwacke and the calcareous schist at the western end of Lake Ritom, rather an artificial one, at all events so far as solubility was concerned; and there may have been no really-insoluble ridge, as he had traced massive calcareous rocks round that end of the lake as far as the gully shown in the photograph, while dolomite came in again still farther round at the lake-level. With this exception, he quite agreed with Prof. Bonney as to the difficulties in accounting for everything by solution. In regard to the excavation of Lago Tremorgio by ice, he had set out fully in the paper the difficulties that he found in accepting this explanation. He thought that the reversal of the Ritom drainage had begun at a much higher level. The lakes, however, did not depend on this.

10. *The* HIGHEST SILURIAN ROCKS *of the* LUDLOW DISTRICT.

By Miss GERTRUDE L. ELLES, D.Sc. (Dublin), and Miss I. L. SLATER, B.A. (Dublin), Newnham College, Cambridge. (Communicated by Prof. T. McKENNY HUGHES, M.A., F.R.S., F.G.S.

Read December 20th, 1905.)

[PLATE XXII—MAP.]

CONTENTS.

I. INTRODUCTION AND BIBLIOGRAPHY.

THE Ludlow district has been regarded as classic ground since the days of Murchison, and, although it has been much neglected by the geologists of more recent times, local collectors of fossils have placed in the Ludlow Museum a collection which is probably unsurpassed for its excellence in illustrating the geology of the neighbourhood.

Many papers were written upon the district by Murchison and others of his time; but, with the exception of Miss Wood's paper on the Lower Ludlow Shales,[1] there has been no revision of its geology since their day: and we are of opinion that the area presents many features of interest, both structurally and otherwise, which can only be brought out by more recent methods of research.

The more important papers dealing with the district are the following:—

MURCHISON, 1834. Proc. Geol. Soc. vol. ii, p. 12.	The earliest definite mention of the rocks of the Ludlow district appears to be found in a paper published by Murchison in 1834. In this he gives the name Ludlow to the beds at the top of the 'Grauwacke Series,' and groups together all the passage-beds into the Old Red Sandstone under the name of 'Tilestones,' which he regards as the lowest division of that Series.
MURCHISON, 1839. 'Silurian System' pp. 196 *et seqq.*	In the 'Silurian System' he gives a few more details respecting these passage-beds, and refers the lower members of them to the Silurian System, under the name of Downton-Castle Building-stone; he also notes the more important localities where they may be studied, and records the discovery of the Bone-Bed in the Upper Ludlow Beds by the Rev. T. T. Lewis
MURCHISON, 1853. Quart. Journ. Geol. Soc. vol. ix, p. 16.	and Dr. Lloyd, the fossil-contents of this bed being described by him in a subsequent paper.

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 415.

MURCHISON, 1854. 'Siluria' 1st ed. pp. 137 *et seqq.* MURCHISON, 1857. Quart. Journ. Geol. Soc. vol. xiii, p. 290.

In 1854 his famous 'Siluria' was published, and in a later paper, dated 1857, in describing the section seen in the Ludlow railway-cutting worked by Lightbody, he notes the existence of what may be a second Bone-Bed, and draws attention to the excellent section exposed in the right bank of the Teme. He considers that the beds in the railway-cutting are faulted against the Old Red Sandstone to the north-west.

EGERTON, 1857. Quart. Journ. Geol. Soc. vol. xiii, p. 282.

In another paper, published in the same year, Sir Philip Grey Egerton dealt with the fish-remains of the Ludlow district.

MURCHISON, 1859. 'Siluria' 3rd ed. chapt. vii.

In the 3rd edition of 'Siluria' Murchison gives an excellent summary of all the work done in the district up to date. He limits the use of the term Tilestones to the upper members of the Transition Series, and uses Downton-Castle Stone as the equivalent of the term Downton Sandstone used by Phillips in the Malvern District. He notes Marston's discovery at Norton of the Lower Bone-Bed, surmounted by beds with *Platyschisma helicites* as the characteristic fossil, and a similar succession made out by Lightbody north of Whitcliffe Coppice. Nevertheless, he does not wish to separate the lower bed from the bed with *Platyschisma helicites.* Also, while acknowledging the apparently higher position in the series of the Bone-Bed found in the railway-cutting, Murchison does not seem to be convinced that it is not the same as the lower one.

HARLEY, 1861. Quart. Journ. Geol. Soc. vol. xvii, p. 542.

In a paper published in 1861, J. Harley gives further evidence of the existence of at least two Bone-Beds, one immediately below and the other just above the Downton Sandstone; he also describes the remains found in them.

CURLEY, 1863. Quart. Journ. Geol. Soc. vol. xix, p. 175. LIGHTBODY, 1863. Quart. Journ. Geol. Soc. vol. xix, p. 368.

T. Curley, writing in 1863, deals chiefly with the superficial accumulations round Ludlow, and illustrates his paper by a small map and a section. Robert Lightbody, writing in the same year, describes a section in the Aymestry Limestone at Mocktree; he also suggests the existence of two faults in the Whitcliffe at Ludlow, throwing up the lower beds.

BRODIE, 1869. Quart. Journ. Geol. Soc. vol. xxv, p. 236.

The Rev. P. B. Brodie describes the Ludlow-Lane section as follows:—(1) Downton Sandstone; (2) *Platyschisma-helicites* Shale; (3) Bone-Bed; (4) Strata with fragments of *Pterygotus*, etc.; (5) Upper Ludlow. He seems to be the first to recognize the *Platyschisma-helicites* Bed at Ludlow, and he regards it as distinct from the lower Bone-Bed.

LIGHTBODY, 1869. Geol. Mag. vol. vi, p. 353.

Lightbody, writing in the Geological Magazine of the same year, suggests the existence of a fault running from the Titterstone to Downton-Castle Bridge, and also infers that the gorge of the Teme at Ludlow is tectonic in origin.

MARSTON, 1870. Geol. Mag. vol. vii, p. 408.

A valuable paper on the beds with which we are dealing was published in 1870 by Alfred Marston, a local Ludlow geologist. In this work the author, although obviously well acquainted with the details of many of the sections in the neighbourhood, contents himself with connecting them together in a generalized account, whereby much of the value of his work is lost.

MARSTON, 1882. 'Guide to the Geology of Ludlow.'

In 1882 the same author published a useful local 'Guide to the Geology of the Ludlow District,' in which the chief localities for fossils are described.

II. Classification.

In the Ludlow-Downton district there exists an interesting series of rocks, limited by the Aymestry Limestone at their base and the Old Red Sandstone at their summit, and it is with these that the present paper deals. Lithologically, they present a varied series of sediments, ranging from limestones on the one hand, through calcareous flagstones and shales, to shallow-water sandstones on the other; and these lithological changes are associated with certain changes in the fauna.

Palæontologically, these rocks are characterized by the presence of Eurypteridæ, which, although rare in the lower beds, gradually increase in importance until they attain their maximum development in the beds immediately underlying the Old Red Sandstone. The rich brachiopod-fauna characteristic of the lower beds dwindles and almost dies out with the approach of shallow-water conditions, although the molluscs are somewhat more persistent.

The recurrence throughout of conditions tending to the formation of 'Bone-Beds' is also worthy of note, such conditions having prevailed at four distinct times at least during the deposition of the rocks with which we are concerned.

As the result of detailed stratigraphical and palæontological work, we believe that we are able to show that these highest Silurian rocks are capable of a certain degree of subdivision, both on lithological as well as on palæontological grounds. Future work will decide whether or not these divisions have a more than local value.

The subdivisions that we would suggest are tabulated on p. 198.

The Aymestry Group takes its name from the well-known locality of Aymestry, 8 miles south-west of Ludlow; its lower member, the massive *Conchidium*-Limestone is, as a rule, full of *Conchidium (Pentamerus) Knightii*, and is thus easily recognized. At Aymestry this limestone is only 75 feet thick; it thickens, however, in a northerly direction, being about 100 feet thick near Ludlow, and as much as 250 feet at Mocktree. The Mocktree or *Dayia*-Shales, which overlie it everywhere, vary according to the thickness of the limestone-bands that they contain; these thicken also to the north, and thus, while only 40 feet thick near Ludlow, have a thickness of 150 feet on Mocktree Hill, whence they derive their name. They are invariably crowded with *Dayia navicula*. These Mocktree Shales seem, as a rule, to have been regarded as forming part of the Upper Ludlow Group, but we are convinced that the brachiopod-fauna is more closely allied to that of the Aymestry Limestone than to that of the higher calcareous beds; and, in addition, *Monograptus leintwardinensis*, which certainly occurs in the Aymestry Limestone, is also found in the highest beds of the Mocktree Shales. Therefore we place the Mocktree Shales in the Aymestry Group.

The Upper Ludlow Group is also capable of a twofold subdivision into the Lower and Upper Whitcliffe Flags. These derive their name from the lofty cliff which forms the right

Purple-red sandstones and marls of the Old Red Sandstone.

III. TEMESIDE GROUP.	F. Temeside or *Eurypterus*-Shales.	*f.* Grey carbonaceous grit = Fragment-Bed. *e.* Olive shales with Eurypteridæ. *d.* Temeside Bone-Bed. *c.* Olive shales, with Eurypteridæ. *b.* Grey micaceous grit. *a.* Variegated rubbly shales and marls, with greenish sandstones at the base.	Zone of *Lingula cornea* and *Eurypterus*.
	E. Downton-Castle or Yellow Sandstones.	*e.* Thinly-bedded micaceous sandstones, with a fish-band and a few *Lingulæ*. *d.* Carbonaceous sandstones. *c.* Massive yellow sandstones, with *Lingula minima*. *b.* *Platyschisma-helicites* Bed, passing laterally into a Bone-Bed. (= Downton Bone-Bed.) *a.* Unfossiliferous sandy shales.	Zone of *Lingula minima*.
II. UPPER LUDLOW GROUP.	D. Upper-Whitcliffe or *Chonetes*-Flags.	*c.* Ludlow Bone-Bed. *b.* Calcareous shales and flags, with *Spirifera elevata* mut. *a.* Calcareous olive-green flags, with *Chonetes striatella*.	Zone of *Chonetes striatella*.
	C. Lower-Whitcliffe or *Rhynchonella*-Flags.	*b.* Concretion-Band. *a.* Calcareous blue flags, with *Rhynchonella nucula*.	Zone of *Rhynchonella nucula*.
I. AYMESTRY GROUP.	B. Mocktree or *Dayia*-Shales.	Shales and thinly-bedded limestones, full of *Dayia navicula*.	Zone of *Dayia navicula*.
	A. Aymestry or *Conchidium*-Limestones.	Massive limestones, with *Conchidium (Pentamerus) Knightii*.	Zone of *Conchidium Knightii*.

bank of the Teme at Ludlow, and in which the entire thickness of the divisions is exposed. The general facies of the fauna is very similar throughout, and there is no very marked difference in lithological character; but, while *Rhynchonella nucula* preponderates in the lower beds, *Chonetes striatella* is the predominant form of the upper member of the group: hence they may be called the *Rhynchonella*-Flags and the *Chonetes*-Flags. So far as we have been able to determine, they do not vary much in thickness throughout the district.

The Temeside Group, as its name denotes, is well exposed along the banks of the Teme, both at Ludlow and in the neighbourhood of Downton Castle; it comprises beds which are virtually passage-beds into the Old Red Sandstone, and may be subdivided into the Downton-Castle or Yellow Sandstones below, and the Temeside Shales above. The term Downton-Castle Sandstone is used practically in the same sense as Murchison's 'Downton-Castle Building-Stone'[1]; while the Temeside Shales include the shales, marls, and grit-bands with *Eurypterus* and *Lingula cornea*, which lie between the Yellow Sandstones and the Old Red Sandstone.

The whole fauna of the Downton-Castle Sandstone, meagre though it be, is more intimately related to that of the Temeside Shales than to that of the beds lying below the Ludlow Bone-Bed. It seems, therefore, advisable to place the beds of this subdivision in the Temeside Group, rather than in the Upper Ludlow Group, with which it has hitherto been classed. The sandstone varies in thickness from 30 to 50 feet from place to place, being thickest near Onibury, but everywhere much thinner than we had been led to believe from various papers.

The Temeside Shales, so far as we have seen, exhibit but slight variation as regards their thickness, such variation as there is being readily accounted for by the thickening or thinning-out of various grit-bands which occur at different horizons in them.

Minimum. Feet.		*Maximum.* Feet.
110	*Eurypterus*-Shales	120
30	Downton-Castle Sandstones	50
150	*Chonetes*-Flags	160
110	*Rhynchonella*-Flags	120
40	*Dayia*-Shales	150
75	*Conchidium*-Limestone	250
515		850

These six major divisions, which constitute six well-defined zones, have been mapped by us throughout the Ludlow district, over an area extending from Ludlow as far south as Overton and Mary-Knowl Dingle, eastward to Caynham Camp, and westward to Downton-on-the-Rock, while our northern boundary runs east and west through Bromfield.

A small map has also been made of the same beds in the neighbourhood of Onibury and Norton, 6 miles north-west of Ludlow (see fig. 8, p. 215).

[1] 'Silurian System' 1839, p. 198.

III. Tectonics.

The main structural features of the district appear to be due to the superposition of two sets of earth-movements—rocks upon which a Caledonian trend had been impressed, being affected at a later time by pressure from the south, the previously-folded beds being held by some rigid mass on the north, presumably that of the Longmynd massif. Hence, the main folds of the neighbourhood of Ludlow, while chiefly due to this (Armorican) movement from the south, run east-north-east and west-south-west, the dips on their northern limbs being everywhere steeper than those on their southern sides.

Along Wenlock Edge the rocks retain their Caledonian trend, and consequently the beds between Wenlock Edge and Ludlow have been dragged round to accommodate themselves as best they may to the later influence.

The faulting is intimately connected with the folding; the main dislocations are of the nature of septal faults, associated with the folds the axes of which run in an east-north-easterly direction. With these are connected a system of relief-faults running in a direction at right-angles to them.

The unyielding nature of the Aymestry Limestone in the west has given rise to a series of dip-faults of accommodation; while in a few places, as for example at Onibury, stresses seem to have found relief along older Caledonian lines.

The main anticline, with an axis running east-north-east and west-south-west through Ludlow town, pitches away to east-north-east; it is cut by an oblique fault all along its northern side, throwing down the beds to the north; with the result that all the different beds of the highest Silurian rocks are brought in turn against the Old Red Sandstone, though the abutting of the Mocktree Shales and Lower Whitcliffe Flags, north-east of Whitcliffe Cottages, is largely helped by the steepness of the ground relatively to the dip at that point.

For the greater part of its course the fault has a downthrow to the north; but, near Downton Castle, where the beds begin to sweep round, the throw gradually changes over to the south side, and appears to die out altogether a little farther west. A well-marked relief-fault, nearly half a mile in length, crosses the river at Downton-Castle Bridge, running a little west of north; while another subsidiary relief-fault, running north 30° east, occurs close to Downton-on-the-Rock. A subsidiary earth-wave finds expression in the Downton-Castle inlier, the intervening trough being occupied by the Old Red Sandstone; while, a little farther north again, a third wave is faintly indicated by the east-north-easterly extension of the main north-to-south line of outcrop.

Lightbody thought that the gorge of the Teme at Ludlow was due to faulting, since the lowest beds seen in the western cliff are not visible in the eastern. He also considered that the structure of the western cliff demanded the existence of two faults. The lower beds

are certainly present in the position noticed by him; but we are of opinion that their presence may be explained by the folding rather than by faulting, and the apparent discordance between the eastern and the western cliff is due to the rapid pitching-away of this fold in an east-north-easterly direction.

The Caynham inlier appears to be part of an anticline faulted on every side. The septal fault on its northern limit is part of a long line of dislocation, extending right across the country from east-north-east to west-south-west, which, like the septal fault to the north, also changes its throw from north to south along its length; a relief-fault truncates the eastern extremity of the inlier, and it appears to be faulted all along its southern side also.

Another fault which ends against the main Caynham dislocation-line runs up Mary-Knowl Dingle, and forms the southern limit of our map; it appears to approximate more closely to a north-west and south-east direction than any of the relief-faults of the Armorican System, and may be an old Caledonian relief-fault affected by the later movement.

IV. Scenery.

The most noticeable feature in the scenery of the district is the marked difference in the character of the country occupied by the Old Red Sandstone and the Silurian rocks respectively. The Old Red Sandstone constitutes, as it were, a plain of arable and pasture-land where the only undulations consist of small isolated hills, due to the presence of cornstones. From this Old-Red-Sandstone plain the Silurian rocks rise everywhere to form wooded slopes of considerable elevation; when the succession is complete, the slope down to the Old Red Sandstone is fairly uniform, but when broken by faults the fall of the ground is usually very abrupt.

From such a structure it follows that there is a tendency on the part of the rivers to cut gorges in the Silurian rocks, while they meander over the country occupied by the Old Red Sandstone; and in only one case have we found that the direction of the drainage is in any way connected with the faulting: this being the course of the River Onny above Onibury.

V. Detailed Description of the Beds.

In describing the geology of the district we have only dealt in detail with those sections which, being more or less continuous, give a real clue to the succession; these may be grouped geographically, as follows:—

i. Sections near Ludlow.
   (*a*) River Teme.
   (*b*) Wigmore Road.
   (*c*) Deerhouse Bank.

ii. Caynham inlier.

iii. Sections near Downton Castle.
   (*a*) River Teme.
   (*b*) North-east of the Castle.

iv. Downton-Castle inlier.

v. Mocktree.

vi. Sections near Onibury.
   (*a*) Craven-Arms Road.
   (*b*) Onibury-Norton Lane.
   (*c*) Norton.

(i) Sections near Ludlow.

Many of the sections in the immediate neighbourhood of the town of Ludlow, referred to by earlier authors, are now completely overgrown or built over, and among these is the famous section in the railway-cutting. Of those that remain, the most complete is that exposed on the right bank of the Teme, from Dinham Bridge to the Sewage-works; this includes the classic section of Ludford Lane and the section in our Temeside Shales referred to by Murchison.[1]

(a) Teme Section.

On the right bank of the River Teme the following beds are seen in ascending order:—

Aymestry Group.—The highest beds of the massive Aymestry Limestone (A) are just seen a little south of Dinham Bridge; they contain *Conchidium Knightii*, *Atrypa reticularis*, *Strophomena euglypha*, *Str. rhomboidalis*, and *Encrinurus punctatus* as characteristic fossils. The Mocktree Shales (B), here about 40 feet thick, may be examined in a small quarry close to the bridge, where they have a general northerly dip at a low angle; and also at the bottom of the track which descends to the river from the Ludlow Arms Hotel, where they dip south-eastward, and the predominant fossil is *Dayia navicula*: *Orthis lunata*, *O. canaliculata*, and *Atrypa reticularis* being also abundant. The whole group is characterized by honeycomb-weathering, due to the concretionary nature of the beds.

Upper Ludlow Group.—The Mocktree Shales are at once succeeded by the lowest members of the Whitcliffe Flags (C). These consist of massive blue calcareous flagstones; they form the base of the Whitcliffe for the greater part of its extent, and are also seen in the lower part of the quarry north of Clive Cottages. They are about 120 feet thick, and are characterized especially by the abundance of *Rhynchonella nucula*; *Orthis lunata* and *Serpulites longissimus* are also highly typical, but *Chonetes striatella* (though present) is rare. These beds contain at their summit a well-marked band of concretions, some of which measure $4 \times 2\frac{1}{2}$ feet; and as this band appears to occur everywhere at the horizon where the *Rhynchonellæ* give place to the *Chonetes* as predominant forms, we have utilized it for purposes of mapping, and take it as marking the highest limit of the *Rhynchonella*-Flags. The greenish calcareous flags (D), which overlie them, are about 160 feet thick: they are somewhat massive at their base, but become more thinly-bedded in their upper portions. The lower beds of these flags are well seen in the great quarry in the face of the Whitcliffe, and also in the face of the cliff between it and Ludford Bridge; but, although the higher beds too are exposed in both places, they are somewhat inaccessible, and may be more easily studied in what was formerly known as 'Ludford Lane,' now termed the Whitcliffe Road.

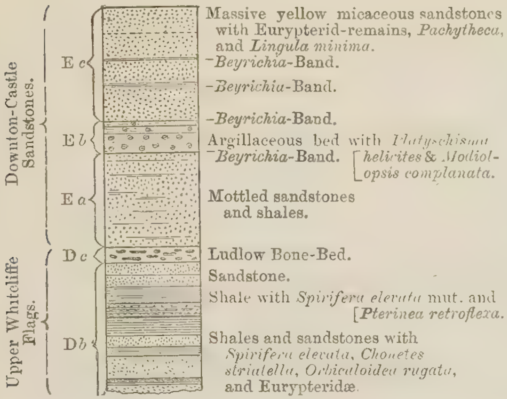
[1] Quart. Journ. Geol. Soc. vol. xiii (1857) p. 290.

The characteristic fossil of these Upper Whitcliffe Flags is pre-eminently *Chonetes striatella*, which literally swarms in them. *Orbiculoidea rugata* and *Orthoceras bullatum* are also abundant; but *Rhynchonella nucula* and *Orthis lunata*, so common in the Lower Whitcliffe Flags, are rare.

The 'Ludford-Lane' section, which is about 72 yards in length, shows the passage between the Upper Whitcliffe Flags and the Downton-Castle Sandstones. These beds are exposed in a high bank, which has a maximum elevation of 12 feet. The general succession is clearest on the northern side, where the beds can be seen dipping south-eastward at 10° (*cf.* vertical section, fig. 1 below).

The lowest beds seen are the *Spirifera-elevata* shales (D *b*); only 4 feet are, however, exposed, consisting of calcareous shales with sandy beds, which contain *Sp. elevata* mut., *Pterinea retroflexa*, and *Pterygotus problematicus*. They are immediately succeeded by the famous Ludlow Bone-Bed (D *c*), which is too well-known to require description. It is best developed at the lower end of the section, on the south side of the road, where it is $2\frac{1}{2}$ feet above road-level, and reaches a maximum thickness of nearly 6 inches. It is, however, very commonly separated into two thin bands of 'bony' material, divided by a few inches of soft mudstone. These bands occur in a more or less lenticular manner, and one or the other disappears almost entirely from time to time, even within the short distance occupied by the section. This feature is characteristic of all the bone-beds of these highest Silurian rocks. In addition to the numerous fish-remains and crustacean remains which the Bone-Bed contains, we have identified *Chonetes striatella*, *Orbiculoidea rugata*, and *Orthis* sp.: a similar fauna, with *Beyrichia* in addition, being found in the softer mudstone separating the 'bony layers.'

Fig. 1.—*Vertical section of the succession at Ludford Lane (Whitcliffe Road), on the scale of 6 feet to the inch.*

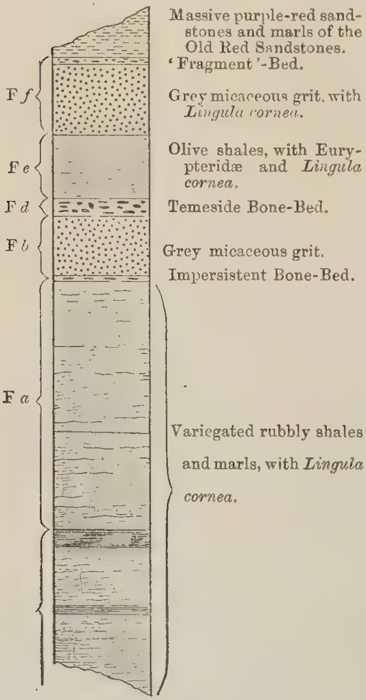


Temeside Group.—The succeeding sandstones (E *a*) differ somewhat in lithology from the beds described above: they are mottled, yellow, slightly-micaceous sandstones, with few traces of life. They seem to usher in new conditions; for, above the Ludlow Bone-Bed,

the articulate brachiopoda, so characteristic of the lower beds, have almost disappeared, *Lingulæ* and the molluscan fauna alone remaining; and we therefore consider that the dividing-line between the Upper Ludlow and Temeside Groups is best drawn at this horizon.

The *Platyschisma*-Bed (E *b*) is practically composed of *Platyschisma helicites* and *Modiolopsis complanata*. *Beyrichia* is also abundant at its upper and lower limits. This bed gives place upward to the typical massive, yellow, micaceous sandstones with *Lingula minima*, which form the bulk of the Downton-Castle Sandstones.

Fig. 2.—*Vertical section of the succession near the footbridge, Sewage-works, Ludlow, on the scale of 6 feet to the inch.*



The higher members of the Downton-Castle Sandstones are not well seen in this Teme section, for, with the exception of the lower beds just described, which are exposed at the lower end of Ludford Lane and in the adjoining Leominster Road, the ground occupied by them is largely built over. They appear to have been worked in an old quarry, in the copse east of Ludford Church, but this is now quite overgrown.

The lowest members of the Temeside Shales (F) visible are seen in two exposures in the river-bank opposite the Gasworks; and, from analogy with other sections, we are of opinion that these are the beds which immediately succeed the highest beds of the Downton-Castle Sandstones. They consist of rubbly shales (seen at water-level) overlain by massive greenish micaceous sandstones with *Lingula cornea*, and with rubbly marls above again (F *a*). For some 250 yards below this the section is interrupted, and no exposures are visible. The section is, however, continued west of the Sewage-works footbridge, where the higher members of the group are extremely-well shown (*cf.* vertical section, fig. 2).

The rubbly grey and red beds (F *a*), the lowest beds observed at this point, appear to correspond very closely in general characters with those seen opposite the Gasworks; 12 feet of these are seen in this lower exposure: they are probably, therefore, of considerable thickness, although there is no direct evidence on this point. The

overlying grit-bed (F *b*), which is conspicuously 'bony' at its lower and upper limits, is here seen at its maximum development (2 feet), but, like the other Bone-Beds of this Series, it thins away rapidly to west and east. Traced westward it almost disappears in the space of a few yards, while traced eastward it diminishes more gradually in thickness, its place being taken by olive shales; so that, close to the footbridge, the grit is only 7 inches thick, the lower of the two 'bony' layers has disappeared, and the upper is present as a thin band in the olive shales (F *c* & F *e*). This Bone-Bed (F *d*), which we designate the Temeside Bone-Bed so as to distinguish it from others at different horizons, is a characteristic feature of the Temeside Shales at this locality, and may be regarded as a grey micaceous grit, in which large fragments of bone and fish-spines are disseminated. There is, in addition, a considerable amount of carbonaceous matter, but whether of vegetable or animal origin is not clear. As a whole, this Temeside Bone-Bed is coarser and more diffuse than the Ludlow Bone-Bed, and very different from the latter in general appearance.

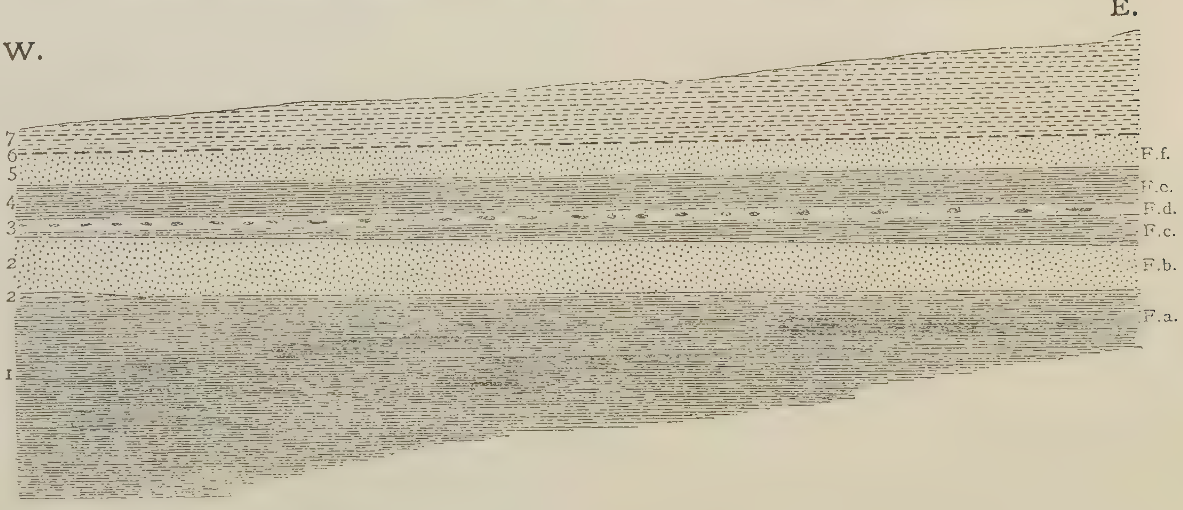
The succeeding olive shales (F *e*) are 2 to 4 feet thick. Eurypterid-remains are abundant, but the majority are too imperfect for determination; these are succeeded by another grey micaceous grit (1 foot), F *f*, at the top of which occurs a well-marked layer crowded with carbonaceous fragments, but in which bones are rare. Purple-red sandstones with shaly partings come on immediately above this 'Fragment-Bed': these differ in general lithology from anything that we have seen at a lower horizon; and since the 'Fragment-Bed' at their base appears fairly constant over wide areas and is easily recognizable, we suggest its adoption as the upper limit of the Silurian System in this district.

On the left bank of the Teme at Ludlow the only rocks now visible are the beds of the Upper Whitcliffe Flags (D), which are well exposed below the Castle. There is, however, a record that the Temeside Shales were exposed in Old Street, when drainage operations were in progress.

(*b*) Wigmore Road.

The Aymestry and Upper Ludlow Groups are again well exposed in Whitcliffe Wood, in a series of small quarries on the east side of the main Wigmore Road. The beds dip northward at angles varying from 10° to 20°. Starting from Mary-Knowl Farm, where the highest members of the Lower Ludlow rocks are seen, the Aymestry Limestones (A) are exposed discontinuously along the road for about 600 yards. The beds show their characteristic honeycomb weathering, and yield their distinctive fauna. The outcrop of the succeeding Mocktree Shales (B) extends over a distance of about 220 yards, where they give place to the Lower Whitcliffe Flags (C). These are seen at intervals down the hill for the next 700 yards, their junction with the Upper Whitcliffe Flags (D) being marked, as usual, by the

Fig. 3.—*Horizontal section in the Temeside Group, near the footbridge, Sewage-works, Ludlow.* (*The section represents a horizontal distance of 300 feet, and the vertical scale is 6 times the horizontal scale.*)



1 = Rubbly shales and marls F *a*.
2′ = Impersistent Bone-Bed } F *b*.
2 = Grey micaceous grit }

3 = { Olive shales F *c*.
{ Temeside Bone-Bed F *d*.
4 = Olive shales F *e*.

5 = Grey micaceous grit } F *f*.
6 = 'Fragment-Bed' }
7 = Old Red Sandstone.

Concretion Band (C *b*). The remaining exposures to the edge of the wood are all in the Upper Whitcliffe Flags (D). Throughout this section the faunas of the beds are quite similar to those furnished by the rocks of the type-section.

(*c*) Stream near Deerhouse Bank.

The best series of exposures on the south-eastern side of the main anticline are seen in the neighbourhood of Deerhouse Bank. The Lower Whitcliffe Flags (C) are exposed along the course of a small stream running east through Ludford Park, the Concretion-Band (C *b*) at its upper limit being seen in an old quarry at the southern end of Deerhouse Bank itself. The Upper Whitcliffe Flags (D) come on immediately above it, and are seen again at the eastern end of the Lower Plantation, succeeded by the lower members of the Downton-Castle Sandstones (E). These are exposed in the northern bank of the old roadway, where a small fault running east-north-east brings on Upper Whitcliffe Flags again to the south. The Downton-Castle Sandstones are, however, better exposed in an old quarry south-east of Huck's Barn, where they dip due eastward at 10°.

(ii) The Caynham Inlier.

In the Caynham inlier, 2 miles east of Ludlow, only the Aymestry and Upper Ludlow Groups are represented, the higher beds being faulted out in every direction. The Mocktree Shales (B), which are the lowest beds visible at this locality, are best seen immediately north of Caynham Camp, and in the old quarries south-west of Poughnhill Cottages. North of Caynham Camp the beds are excavated in the centre of the dome, which is abruptly truncated on the north, the strata being much disturbed close to the fault and dipping at 50°. The *Rhynchonella*-Beds (C *a*) of the Lower Whitcliffe Flags occupy the greater part of the remainder of this inlier, being seen all along the southern face of the hill from the eastern boundary-fault to Saltmore, a distance of about 2½ miles. They are exposed in a series of small quarries, where the dip when close to the southern fault may be 30° south-eastward. The Upper Whitcliffe Flags (D) are seen only at the Saltmore end of the inlier, and are best exposed in an old quarry east of the railway.

(iii) Sections near Downton Castle.

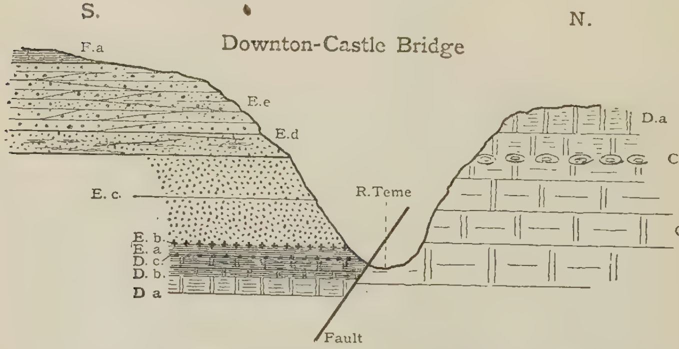
(*a*) Teme Section, between Bow Bridge and Downton-Castle Bridge.

One of the finest sections in the district is exposed in the neighbourhood of Downton Castle, along the banks of the Teme between Bow Bridge and Downton-Castle Bridge, there being an almost continuous exposure of rock between these two localities.

On the northern bank, due south-west of Bow Bridge, the Aymestry Limestones (A) are extensively quarried along a grand

cliff-face; they dip 20° northward, and, as usual, *Conchidium (Pentamerus) Knightii* is the characteristic fossil, associated with *Strophomena euglypha*, *Wilsonia Wilsoni*, *Atrypa reticularis*, and other forms. These beds are also seen on the southern bank south-east of the bridge. In the immediate neighbourhood of the bridge they are succeeded by the Mocktree Shales (B), crowded with *Dayia navicula*. These are seen to bend round quickly at the edge of the syncline, and dip eastward (downstream) at a low angle. These Mocktree Shales extend as far as the Hay Mill on the southern bank, but for a slightly-shorter distance on the north side, where a steeply-rising cliff brings on the massive *Rhynchonella*-Beds (C), down to water-level. Beyond the Hay Mill, these *Rhynchonella*-Beds form cliffs on both sides of the river for half a mile, where they are succeeded by the *Chonetes*-Beds (D). At the Weirs a fault runs obliquely across the stream, causing a repetition of the *Rhynchonella*-Beds on the north side; they extend thence to Downton-Castle Bridge at the base of the high cliff, the upper portion of which is formed of the *Chonetes*-Beds.

Fig. 4.—*Diagrammatic section across the Teme at Downton-Castle Bridge.*



C a=Calcareous blue flags, with *Rhynchonella nucula*.
C b=Concretion-Band.
D a=Calcareous olive-green flags, with *Chonetes striatella*.
D b=Calcareous shales and flags with *Spirifera elevata* mut.
D c=Ludlow Bone-Bed.
E a=Unfossiliferous sandy shales.
E b=*Platyschisma-helicites* Bed.
E c=Massive yellow sandstones, with *Lingula minima*.
E d=Carbonaceous sandstones.
E e=Thinly-bedded micaceous sandstones.
F a=Variegated rubbly shales and marls, with greenish sandstones at the base.

On the south side of the river the *Chonetes*-Beds form the base of the cliff, which is capped by the Downton-Castle Sandstones (E), and close to Downton-Castle Bridge the *Spirifera-elevata* Beds (D b) succeed the Lower *Chonetes*-Beds (D a), and are surmounted at road-level by the Ludlow Bone-Bed (D c). The *Spirifera-elevata* Beds are about 12 feet thick at this locality, and contain a band swarming with *Crania implicata*.

Two feet above road-level the *Platyschisma*-Bed (E *b*), which is here 'bony,' may be noted (= Downton Bone-Bed): and at the commencement of the river-path, on the eastern side of the road, the basal members of the Temeside Shales (F) may be observed: they are obviously disturbed by the proximity of the fault, and plunge down steeply towards it.

The basal Temeside Shales (F *a*), consisting of rubbly shales associated with greenish micaceous grits and containing *Lingula cornea*, are also well-exposed along the road running southward from the bridge, and again on the top of the hill to the west of it, along the track leading to Burrington Hays. Farther south-west along this same track, the Downton Bone-Bed and the Ludlow Bone-Bed too are seen once more.

(*b*) North-east of Downton Castle.

Another confirmatory section is also to be found along a road which leaves the main road to run north-west and south-east, along a gully between Downton-Castle garden and the Brakes Wood.

In the main road close to the Downton-Castle lodge the *Chonetes*-Beds (D) are well seen, dipping at 8° S. 10° E.; while close below the main road, where the side-road makes a big bend, the *Spirifera-elevata* Beds (D *b*) are exposed. A few yards farther east the Downton-Castle Sandstones (E) come on, and have been extensively quarried on both sides of the gully. The most interesting exposure is that seen on the south side, where an excellent junction between the Downton-Castle Sandstones and the Temeside Shales may be studied. At the northern end of this quarry, about 20 feet of Downton-Castle Sandstones may be seen, the upper 11 feet being the thinly-bedded micaceous sandstones (E *e*), while the lowest beds seen are the carbonaceous sandstones (E *d*). A deeply-weathered band 6 feet from the top may represent the Fish-Bed, but it is not clearly defined. The highest members of the thinly-bedded sandstones acquire a greenish tint and mealy texture, and pass gradually up into the rubbly shales (F *a*), 15 feet of which are exposed at the southern end of the quarry. The section is then obscured for some little distance, but at the corner where the road bends more to the south-west, the olive shales with the Temeside Bone-Bed (3 inches thick) may be observed; while, in a small quarry east of the Schoolhouse, the Old Red Sandstones are seen.

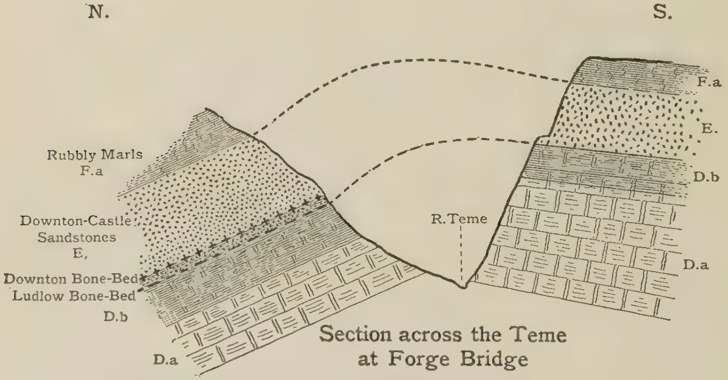
(iv) The Downton-Castle Inlier.

In this inlier there is a practically-complete succession of the highest Silurian rocks, from the *Chonetes*-Beds of the Upper Ludlow Group into the Old Red Sandstone.

Upper Ludlow Group.—The lowest members seen are the *Chonetes*-Beds (D *a*). These are exposed on the southern bank of the Teme north-east of Forge Bridge, where they dip south-eastward at a low angle, forming the lowest portion of a steep cliff some 60 feet in

height. The succeeding *Spirifera-elevata* Beds (D *b*) are about 12 feet thick; but the Ludlow Bone-Bed (D *c*) appears to be overgrown by vegetation wherever the cliff is accessible: its position, however, can be approximately determined, since the *Spirifera-elevata* Beds are found about 40 feet above water-level, while the lowest members of the Downton-Castle Sandstones (E) are seen a few feet above.

Fig. 5.



[For explanation, see the vertical section, fig. 6, p. 212.]

On the other side of the river the succession is clearer: the *Chonetes*-Beds again form the base of the cliff both east and west of Forge Bridge, dipping north-westward; and, owing to the unsymmetrical nature of the fold, the Ludlow Bone-Bed is visible at a lower level, being seen in the road leading down to the bridge, along a track leading to Forge Rough, and again farther to the north-east, close to a cottage by the Old Millrace-weir.

Temeside Group.—At all these localities the *Platyschisma*-Bed (E *b*) is found, in its usual position, with the intervening 3 feet of mottled sandstone between it and the Ludlow Bone-Bed. In the road-section it is slightly 'bony' in character; but at the Cottage it has taken on all the characteristics of a bone-bed, and so closely resembles the Ludlow Bone-Bed that it can only be distinguished by the presence of *Platyschisma*, which still occurs abundantly and has never been found by us at the lower horizon. From the Cottage this *Platyschisma* Bone-Bed (=Downton Bone-Bed) strikes down towards the River Teme, and is seen at river-level about 100 yards farther east. The beds immediately above it are the massive yellow sandstones with *Lingula minima* (E *c*). The higher members of the Downton-Castle Sandstones form the remainder of the cliff on the north side of the river, but are only well exposed in the quarries on either side of the road leading to the bridge, where the highest sandstones (E *e*) are seen. The entire thickness of these sandstones does not seem to exceed 35 feet at this locality, although there is a little variation from place to place. The beds gradually bend round

to the south, and 200 yards west of the bridge strike so as to cross the river.

On the southern bank, the Downton-Castle Sandstones are seen just behind the Forge, and up the banks of a small stream which flows northward into the river at this locality; but the best section is seen in a large quarry at the top of the southern cliff, where a path runs along in the Tin-Mill Wood, at a height of 45 feet above the river.

Here 22 feet of sandstones are exposed, dipping southward at 7°. The lowest beds seen are the massive sandstones (E *c*), but their base is not visible; they are succeeded by the carbonaceous sandstones (E *d*), which are in turn overlain by the thinly-bedded micaceous sandstones (E *e*). About 7 feet from their upper limit a coarse micaceous bed seems to represent the Fish-Bed, but the fish-remains are not so abundant as at some other localities. The sandstones above it gradually acquire a greenish tint, and a more mealy texture, and pass gradually up into the rubbly shales (F *a*) so characteristic of the highest division of these rocks. (*Cf.* vertical section, fig. 6, p. 212.) This is one of the best sections in the district for showing the junction between the Downton-Castle Sandstones and the Temeside Shales.

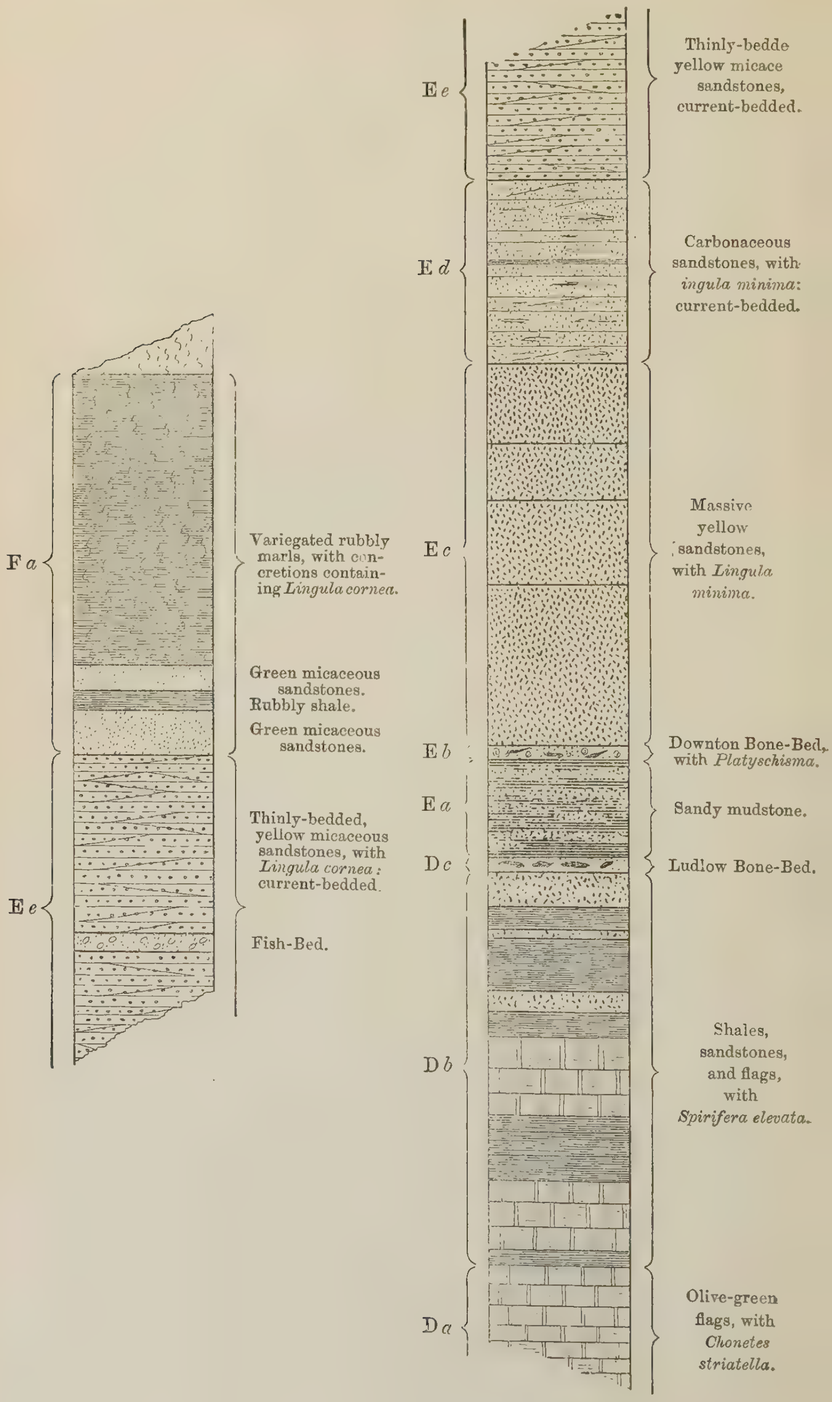
Continuing north-east through the Tin-Mill Wood, and following the lower track where the path divides, one may again see the higher members of the Downton-Castle Sandstones (E *e*) in several small quarries. The strike of the beds sweeps round gradually in a northerly direction, until beyond the old Tin-Mill the beds dip north-east at 8°.

In the low cliff which forms the right bank of the Millrace an excellent section of Temeside Shales is exposed, passing up into the Old Red Sandstone (*cf.* vertical section, fig. 7, p. 213). The bed of the Millrace is occupied by soft grey flaggy beds (F *a*), but these can only be observed in dry weather, and are usually covered by water; the higher beds of the rubbly shales are seen at the side. A red shale-band is conspicuous near the base of the low cliff, and about 2 feet above it a gritty bed with broken *Lingulæ* is found: this is easily recognizable, and seems to be a local bone-bed; it has yielded *Lingula cornea*, *Onchus tenuistriatus*, *Ctenacanthus*-like spines, and *Leperditia* cf. *marginata*.

The hard grey sandstone (F *b*) forms a well-defined ledge all along the section, and is succeeded by a grey shale-bed, from the weathered surface of which large specimens of *Lingula cornea* often project in great abundance. These pass up into the more typical olive shales with the Temeside Bone-Bed (F *d*). In its general characters, this bone-bed is exactly comparable with that exposed on the River Teme at Ludlow. It is very fossiliferous at this locality, and has yielded the following forms:—

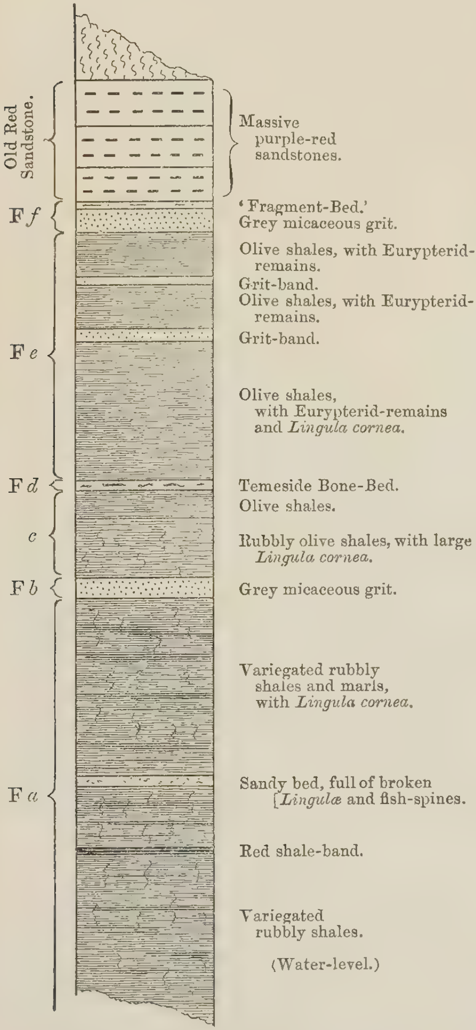
Pterygotus ludensis.
Pterygotus problematicus.
Onchus tenuistriatus.
Onchus Murchisoni.
Onchus sp.
Lingula cornea.
Ctenacanthus sp. (?)
Cephalaspis sp. (?)
Pachytheca sphærica.

Fig. 6.—*Vertical section of the Downton-Castle inlier at Forge Bridge, on the scale of 6 feet to the inch.*



The olive shales are also very fossiliferous, and contain numerous remains of Eurypteridæ, most of which are, however, very fragmentary, as the beds are brittle and have an objectionable habit of crumbling to pieces when worked. At the top of the olive shales gritty bands begin to come in, and a well-defined one crowded with carbonaceous remains is recognizable as the 'Fragment-Bed'; while immediately above it come the massive purple-red sandstones, which we regard as belonging to the Old Red Sandstone.

Fig. 7.—*Vertical section in the Temeside Group at Tin-Mill Race, on the scale of 6 feet to the inch.*



The Temeside Shales are also exposed at three other places in the inlier; on the north side at the Spring, where the rubbly shales alone are visible, and on the south side in the small stream near Forge Bridge, and west of the bridge below the track leading to Downton-Castle Bridge. In the stream the following beds were seen:—

The variegated rubbly beds (F *a*) are exposed in the stream-bed for a short distance, and terminate at a small waterfall which marks the position of the grey micaceous grit (F *b*). The lowest olive shales are not seen, but the highest beds may be detected below the massive red sandstones, the position of which is indicated by another waterfall. All the beds dip a little east of south at 25°.

The succession of these highest beds is more clearly seen 300 yards west of the stream below the track to Downton-Castle Bridge. Here the olive shales are well exposed, with the characteristic gritty 'Fragment-Bed' at their upper limit. We were unable to detect this in the stream-section, but it is here immediately overlain by the same massive red sandstones as those which form the upper waterfall of the stream.

The chief points wherein these beds in the neighbourhood of Downton Castle differ from those at Ludlow, are the thinning of the *Platyschisma*-Bed to a Bone-Bed and the thickening of the olive shales (F *c* & F *e*).

(v) Mocktree.

Owing to the faulting in the northern part of the area, a satisfactory line of section is difficult to obtain, but a fairly typical one can be made out along the Leintwardine-Ludlow road.

The Aymestry Limestones (A) are still being worked in a series of quarries along that part of the road which runs through Wassell Wood; but in the large quarry 130 yards west of the Briery a small fault running from north-west to south-east drops the Mocktree Shales (B) down against the limestones, and the fault is well seen in the face of the quarry. The lowest limit of the Mocktree Shales is also visible and is somewhat peculiar, suggesting that at this horizon erosion of the limestones was being carried on during their deposition.[1] This section has been recently figured in the Proceedings of the Geologists' Association, vol. xviii (1904) pl. xlii, fig. 1.

The Mocktree Shales, crowded with *Dayia navicula*, are exposed more or less continuously for 600 yards along the road, but then the succession is interrupted by a west-north-west fault, and consequently the same beds are still seen for another quarter of a mile along the road. They are more extensively developed here than anywhere else in the district, attaining a maximum thickness of 150 feet. On each side of Fiddler's Elbow the basal beds of the Lower Whitcliffe Flags (C) are seen, and south-east of Hillpike Farm Upper Whitcliffe Flags (D) are well displayed in an old quarry on the south side of the road, and in the banks of the road itself. On the north side of the road near Lodge Lane, the highest members of the Downton-Castle Sandstones (E) have been quarried in a small plantation.

(vi) Sections near Onibury.

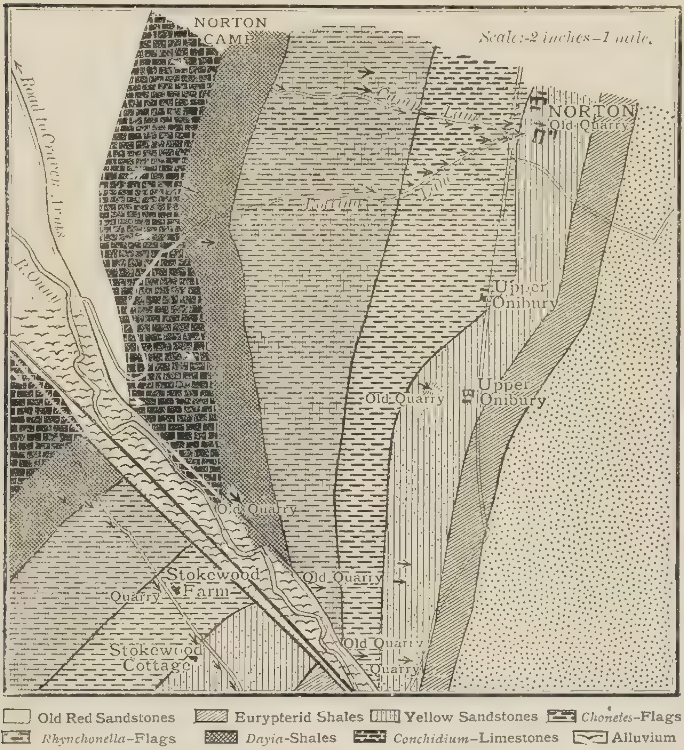
(*a*) Craven-Arms Road.

Another section showing the relationships of the highest Silurian rocks may be seen along the road from Craven Arms to Onibury, 6 miles north-west of Ludlow. The Aymestry Limestones (A) are exposed a little more than a mile north-west of Onibury, on the north side of the road, dipping 15° eastward; and from this point to the milestone there is a nearly-continuous exposure in the road and in the river-bank, along which the characteristic honeycomb-weathering is most clearly seen. The succeeding Mocktree Shales (B) are well

[1] Lightbody, Quart. Journ. Geol. Soc. vol. xix (1863) p. 368.

exhibited in an old quarry off the road, and again in the river-bank to the south-east. The lowest beds of the Lower Whitcliffe Flags (C) are not exposed, but the higher members may be studied in an old

Fig. 8.—*Geological map of the neighbourhood of Onibury.*
(The map is oriented north and south.)



quarry in the wood west of Upper Park Farm; while the Upper Whitcliffe Flags (D) are still worked farther south in another old quarry, where the Concretion-Band (C *b*) is visible 6 feet from the base.

(*b*) Onibury-Norton Lane.

Crossing the railway at Onibury and taking the lane leading to Norton, a large quarry in the Downton-Castle Sandstones (E) is seen 200 yards above the post-office on the west side of the road. Some 32 feet of rock are exposed, and the beds dip E. 15° S. at 12°, but neither the highest nor the lowest beds are visible. (*Cf.* vertical section, fig. 9, p. 216).

The lowest beds seen are the massive sandstones (E *c*), but they are only exposed for a few feet in the south side of the quarry, where working has been carried on to a lower level than elsewhere; their massive bedding and irregular fracture are characteristic, and

Fig. 9.—*Vertical section in the Downton-Castle Sandstones at Onibury Quarry, on the scale of 6 feet to the inch.*

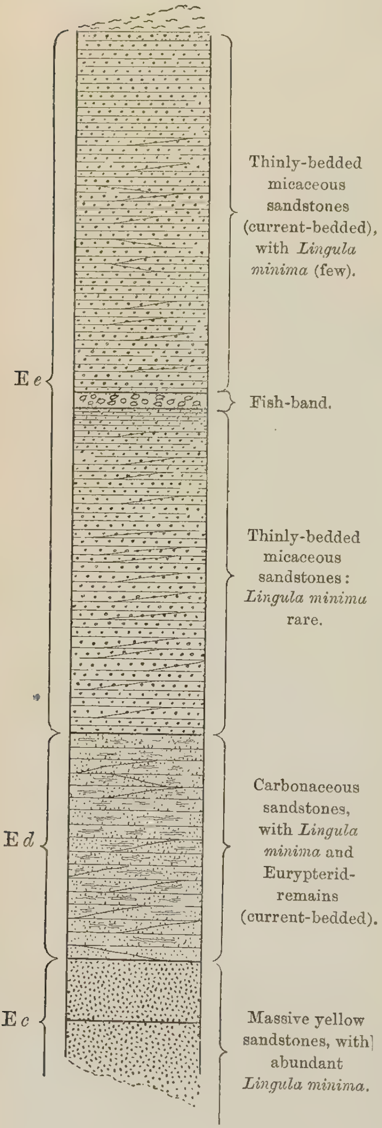
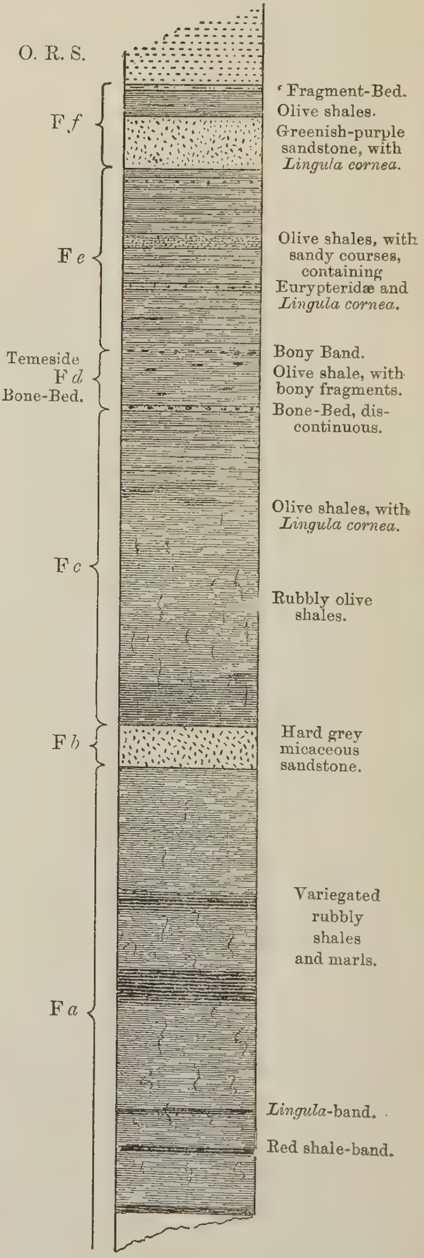


Fig. 10.—*Vertical section in the Temeside Shales in Norton Lane, on the scale of 6 feet to the inch.*



they contain numerous specimens of *Lingula minima*, while *Leperditia marginata* and various seed-like bodies are also found. These massive sandstones pass up into others chiefly distinguished by their more regular and closer bedding, smaller number of *Lingulæ*, and abundant carbonaceous remains. These and the succeeding division are markedly current-bedded. The carbonaceous remains become rarer in the higher beds, and the bedding becomes thinner, so that the highest sandstones are uniformly thinly-bedded, extremely-micaceous sandstones, with but few traces of life except in the peculiar bed that we have distinguished as the Fish-Bed.

This Fish-Bed occurs about 12 feet down, and is well seen in the western face of the quarry: it is a coarsely-micaceous friable sandstone, full of fish-fragments, which show especially clearly on the weathered surface. It varies both in texture and thickness within short distances, and in this respect agrees closely with the various Bone-Beds of the Series. It does not seem to be present everywhere over the area, but wherever we have detected it, it occupied approximately this same horizon.

The fish-remains collected from this bed were unfortunately very fragmentary and badly preserved. Our debt therefore is all the greater to Dr. Traquair and Dr. Smith Woodward for their kindness in examining them for us. They report that most of the fish-remains are broken-off cornua of the Cephalaspid *Eukeraspis pustulifera*, Agassiz, while a few are fragmentary spines referable to the Acanthodian genus *Climatius*.

Continuing in a north-easterly direction along Norton Lane, we find the next exposure about 80 yards farther up on the east side of the road in the ditch, where the rubbly shales (F *a*) are seen; they are precisely like their equivalents in the Tin-Mill Wood, and must be those immediately overlying the highest beds of the Downton-Castle Sandstones.

About 300 yards farther up the lane, just before it turns abruptly to the left, is the beginning of one of Marston's typical sections. The Temeside Shales are seen on both sides of the road, and although somewhat overgrown, the section is more or less continuous, and affords an excellent opportunity for studying the succession, which appears to be as follows (*cf.* vertical section, fig. 10, p. 216):—

The lowest beds seen are the variegated rubbly shales (F *a*), 15 feet of which are exposed: among these may be noted a conspicuous red shale-band, 2 feet above road-level, and a *Lingula*-band 1 foot above the shale-band. The hard grey grit (F *b*) forms a conspicuous ledge all along the section on both sides of the road; the succeeding olive shales (F *c*) are considerably thicker than their equivalents in the Tin-Mill Wood; and the Temeside Bone-Bed is found well up in them. This bone-bed is perhaps less clearly defined than usual, consisting of two distinctly 'bony' layers, with bony fragments in the intervening shale as well; probably the three layers should be regarded as the equivalent of F *d* elsewhere. Numerous fossils have been obtained at this locality (see lists, pp. 219–20).

The greater thickness of the higher beds of the olive shales

appears to be due to the presence of sandy beds, which are hardly represented in the Tin-Mill Wood.

Just below the lowest of a series of purplish sandstones the 'Fragment-Bed' may be found. Therefore we place all the beds of the upper part of the section in the Old Red Sandstone, although, so far as we can make out, Marston included them in his 'Tin-Mill Shales.'

(c) Norton.

Additional confirmatory sections are visible in the tracks leading from Norton-Camp Wood to Norton, known as Rotting Lane and Camp Lane respectively.

The Aymestry Limestones (A) have been extensively quarried in Norton-Camp Wood; they yield their characteristic assemblage of fossils, although *Conchidium (Pentamerus) Knightii* is perhaps not so abundant as at some other localities, and *Atrypa reticularis* rather more so. The Mocktree Shales (B) are seen at various points immediately east of the Wood, and the Lower Whitcliffe Flags (C) come on quickly above them, and are well seen in Rotting Lane with the Concretion-Band (C *b*) which marks their upward termination. The Upper Whitcliffe Flags (D) are seen in continuous section along both tracks, dipping 6° eastward, the *Spirifera-elevata* Beds coming on just before the main road is reached. The Ludlow Bone-Bed (D *c*) is exposed in the orchard behind the red cottage, a few yards to the north. It is better developed here than anywhere else in the district, being both thicker and richer in organic remains than in other localities known to us. The *Platyschisma*-Bed (E *b*) occurs above it, with only 2 feet of mottled sandstone intervening.

The massive sandstones (E *c*) have been quarried behind Norton Farm, and are there seen with the carbonaceous beds (E *d*) resting upon them. The outcrops of the highest members of the Downton-Castle Sandstones and all the Temeside Shales are concealed by vegetation.

VI. Conclusions.

We hope to have shown in the foregoing pages that the highest Silurian rocks are capable of more detailed subdivision than has been hitherto believed. It remains, however, to be proved whether the classification that we have adopted is of more than local value, although from the observations of one of us in other areas we have some reason to hope that this will prove to be the case.

The mapping of our zones has also, we think, indicated in various places the presence of faults which have remained hitherto undetected.

In conclusion, we offer our grateful thanks to Prof. Hughes for facilitating our work in every way; to Dr. Marr for his advice and encouragement; and to all the other members of the Cambridge School, with whom various points have been freely discussed. We would also wish to record our gratitude to Mr. Charles Fortey, the honorary Curator of the Ludlow Museum, for his unfailing courtesy to us during our visits to that town.

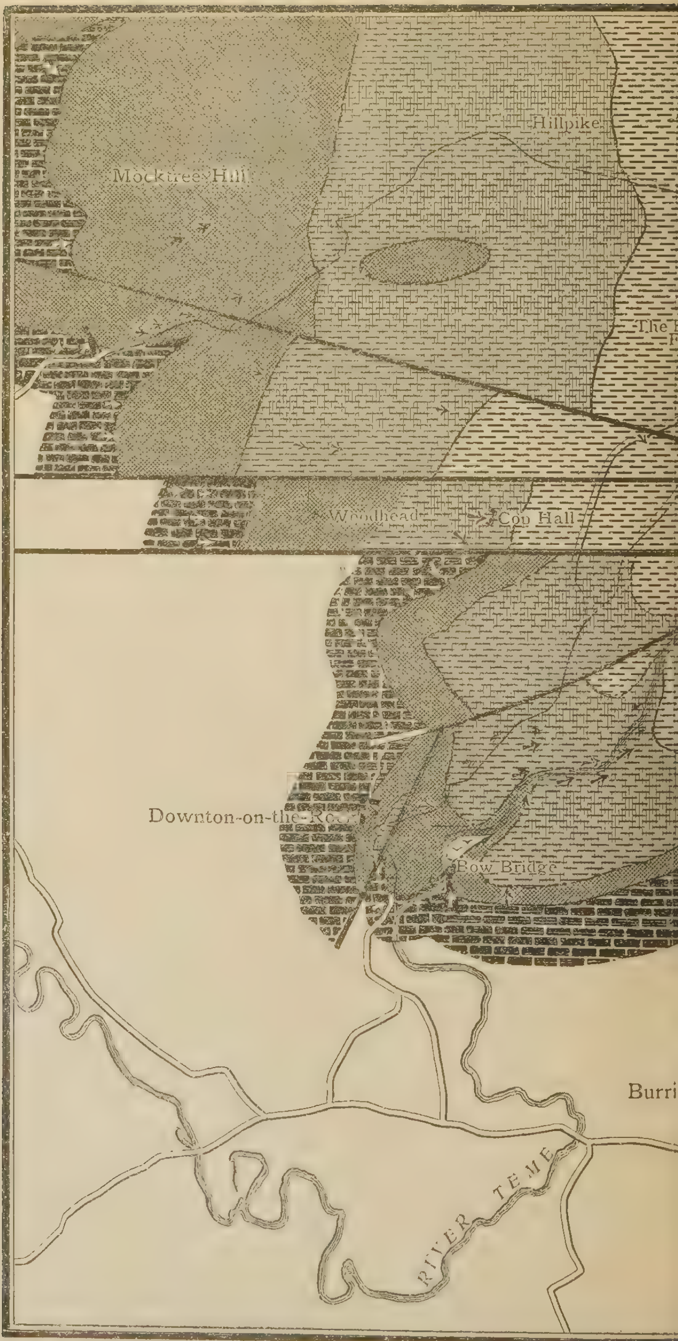
VII. Fossil Lists.

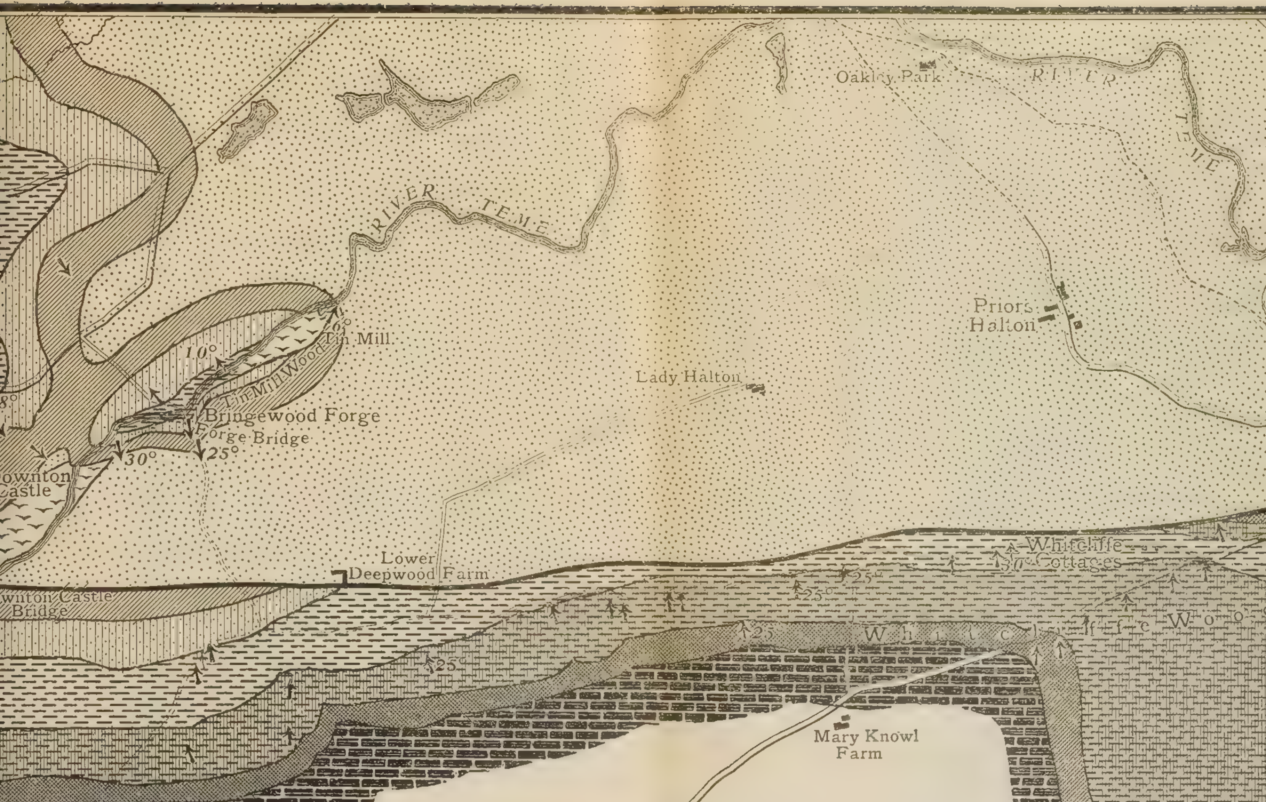
[These lists are compiled from our own collections, supplemented by that of the Ludlow Museum.]

r = rare. c = common. C = very common.	Aymestry Group.		Upper Ludlow Group.				Temeside Group.									
	Conchidium-Limestone.	*Dayia*-Shales.	*Rhynchonella-nucula* Beds.	*Chonetes*-Beds.	*Spirifera-elevata* Beds.	Ludlow Bone-Bed.	Mottled Beds.	*Platyschisma*-Bed.	Massive sandstones.	Carbonaceous sandstones.	Thinly-bedded sandstones.	Variegated rubbly shales.	Micaceous grit.	Olive shales.	Temeside Bone-Bed.	'Fragment-Bed.'
Brachiopoda.																
Lingula cornea, Sow.	...	...	...	...	...	...	...	...	...	...	...	c	c	C	c	c
L. lata, Sow.	c	c														
L. Lewisii, Sow.	...	...	c	C	c	r										
L. minima, Sow.	...	...	..	...	...	r	r	c	C	c	r	r				
Orbiculoidea rugata, Sow.	...	...	?	C	c	r										
O. striata, Sow.	...	..	r	r	r	r										
Crania implicata, Sow.	...	...	r	r	C											
Pentamerus (Conchidium) Knightii, Sow.	C															
Strophomena euglypha, His.	C	c														
Str. rhomboidalis, Wilck.	C	c														
Str. ornatella, Salter	C	c														
Orthis orbicularis, Sow. } *O. canaliculata*, Lindstr. }	C	C	c	c												
O. lunata, Sow.	C	C	C	c	c	r										
O. cf. *elegantula*, Dalm.	c	c	c	c	c	r										
Atrypa reticularis, Linn.	C	C														
Chonetes minima, Sow.	...	...	r	r	r											
Ch. striatella, Dalm.	...	..	c	C	C	c										
Ch. lepisma, Sow.	...	...	r	r	r											
Rhynchonella nucula, Sow.	...	r	C	c	c											
Rh. (Wilsonia) Wilsoni, Sow.	C	c	r													
Dayia navicula, Sow.	r	C														
Spirifera elevata mut., Dalm.	...	...	...	r	C											
Whitfieldella didyma, Dalm.	C	c														
Lamellibranchiata.									Various small undeterminable Lamellibranchiata.			Various small undeterminable Lamellibranchiata.				
Avicula Danbyi, M'Coy.	r	r	r	r												
Cucullella antiqua, Sow.	...	...	...	r												
C. coarctica, Phill.	r	r														
C. ovata, Sow.	r	r	r													
C. sp.	...	r	r	r	r											
Ctenodonta sp.	...	...	r													
Goniophora cymbæformis, Sow.	...	...	C	C	C											
Modiolopsis complanata, Sow.	...	...	...	...	...	...	...	C								
M. lævis, Sow.	...	...	...	c	c											
M. mytilimeris, Conrad	...	...	..	c												
M. sp.	...	...	r													
Orthonota amygdalina, Sow.	r	...	...	C	c	r										
O. amygdalina var.	...	...	...	c	c											
O. angulifera, M'Coy	...	...	.	c												
O. impressa, Sow.	...	...	..	c												
O. rigida, Sow.	...	..	...	c												
O. semisulcata, Sow.	...	..	..	c												
O. solenoides, Sow.	..	..	.	c	c											
Pterinea hyans, M'Coy	...	...	c													
Pt. orbicularis, M'Coy	r	r														
Pt. retroflexa, Wahl	...	.	C	C	C											
Pt. tenuistriata, M'Coy	r	r														
Gasteropoda.																
Bellerophon expansus, Sow.	r	r	c	c												
B. Murchisoni, d'Orb.	...	..		r	r											
B. wenlockensis, Sow.	c															
Cyclonema corallii, Sow.	...	r	r	r												
Holopella gregaria, Sow.	...	..	..	..	..	r	..	c								
H. obsoleta, Sow.	...	...	r	r	r											
H. sp.	...	..	..	r												
Murchisonia articulata, Sow.	...	.		c												
Platyschisma helicites, Sow.								C								

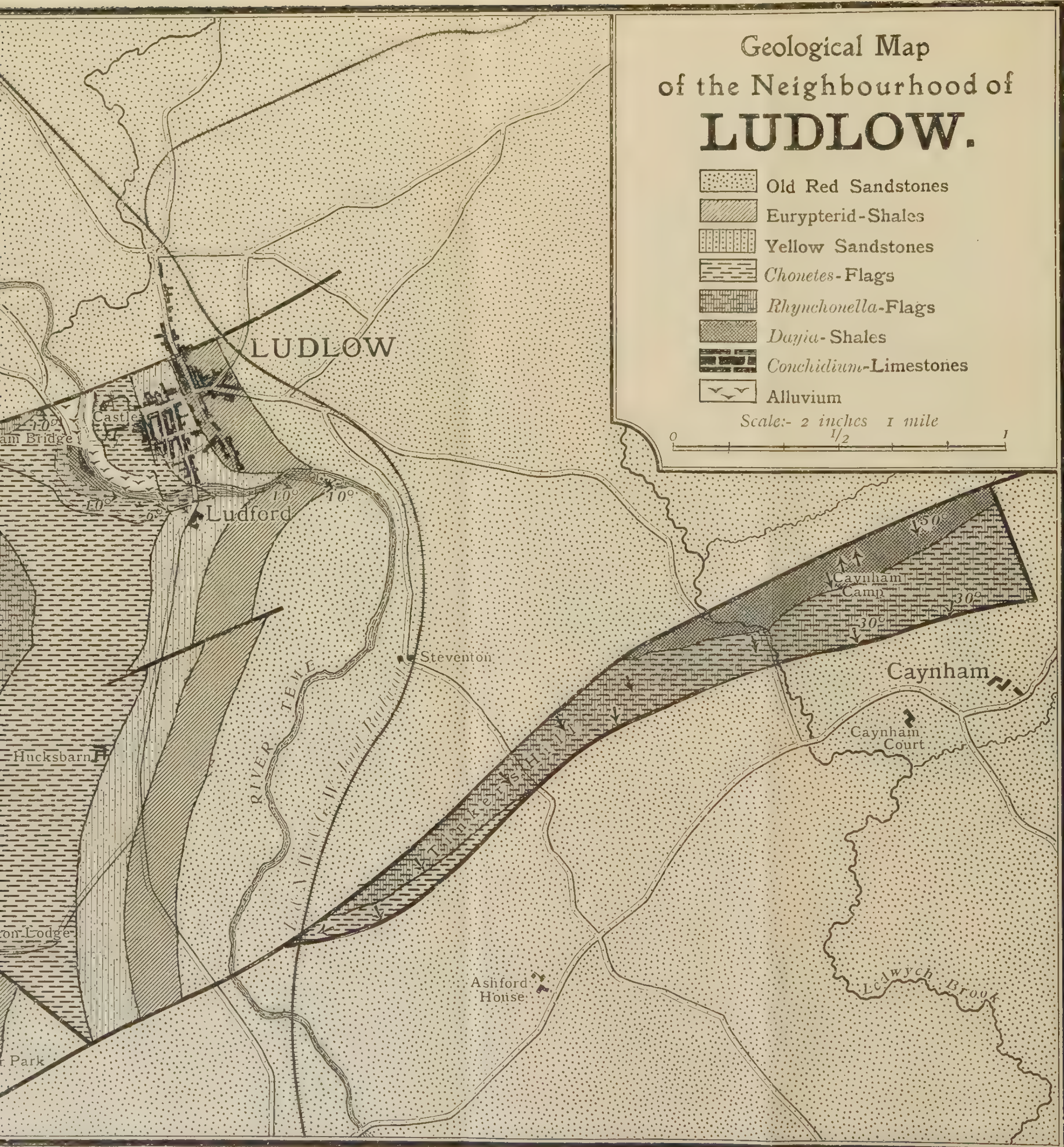
r = rare.
c = common.
C = very common.

	Aymestry Group.		Upper Ludlow Group.				Temeside Group.									
	Conchidium-Limestone.	*Dayia*-Shales.	*Rhynchonella-nucula* Beds.	*Chonetes*-Beds.	*Spirifera-elevata* Beds.	Ludlow Bone-Bed.	Mottled Beds.	*Platyschisma*-Bed.	Massive sandstones.	Carbonaceous sandstones.	Thinly-bedded sandstones.	Variegated rubbly shales.	Micaceous grit.	Olive shales.	Temeside Bone-Bed.	'Fragment-Bed.'
CEPHALOPODA.																
Orthoceras bullatum, Sow.	...	...	c	C												
O. gregarium, Sow.	.	...	c	C												
O. ludense, Sow.	...	...	c	c												
O. sp.	...	...	...	c	c											
Lituites ibex, Sow.	...	...	...	c												
ACTINOZOA, etc.																
Chætetes sp.	...	...	...	c												
Aulopora serpens, Linn.	C	c														
Favosites Forbesi, M.-Edw.	C	c	c	c												
Stenopora fibrosa, Goldf.	c	c	c	c	c											
Spongarium Edwardsii, Murch.	C	c														
VERMES.																
Cornulites serpularis, Schloth.	...	...	...	c	c											
Serpulites longissimus, Murch.	...	...	c	c												
Spirorbis Lewisi, Sow.	...	...	...	r												
Trachyderma coriaceum, Phill.	...	...	c	c												
PLANTÆ (?)																
Pachytheca sphærica, Hooker.	...	...	...	r	r	...	...	c	C	...	...	...	...	C	C	C
CRUSTACEA.																
Calymene Blumenbachii, Brong.	c	r														
Encrinurus punctatus, Brünn.	c	r	r													
Homalonotus Knightii, König	...	...	...	C	c											
Phacops sp.	...	...	...	...	c											
Eurypterus acuminatus, Salt.	...	...	...	...	r	...	...	...	...	...	...	...	...	r		
Eur. linearis, Salt.	...	...	...	...	r											
Eur. pygmæus, Salt.	...	...	...	...	...	...	...	...	...	...	...	...	...	c		
Eur. megalops, Salt.	...	...	...	...	...	...	...	...	...	...	...	...	...	c		
Eur. spp. various	...	...	...	r	...	r	...	...	c	...	...	c				
'*Parka decipiens*' (eggs)	...	...	...	...	...	...	...	...	...	...	...	...	c	c		
Pterygotus Banksii, Salt.	...	...	...	...	...	r	...	c	...	...	...	...	...	c		
Pt. gigas, Salt.	...	...	...	...	...	...	...	...	r	...	...	...	...	c	c	
Pt. ludensis, Salt.	...	...	...	...	...	...	...	...	...	...	...	...	...	c	c	?
Pt. problematicus, Ag.	...	?	r	r	r	r	...	r	c	...	...	...	...	c	c	?
Beyrichia Klœdeni, M'Coy	...	...	C	C	C	...	r	C	c	c	c	c	c	c	c	
B. sp.	...	...	...	c	c	r	...	C								
Leperditia marginata, Keys.	...	...	...	...	...	...	...	...	...	...	...	c	...	c	...	c
L. phaseolus, var. *gracilenta* (Jones)	...	...	...	...	...	...	...	...	...	...	...	...	...	r		
L., small species	...	...	...	...	c	c	...	...	...	...	...	c	...	c		
Physocaris vesica, Salt. ?	...	...	...	...	...	...	...	...	...	...	...	...	...	c	c	
PISCES.																
Auchenaspis Salteri, Egerton	...	...	...	...	...	...	...	...	...	...	...	...	...	r		
Cephalaspis Murchisoni, Egert.	...	...	...	...	...	?	...	...	...	...	?	...	...	r	r	
Climatius	...	...	...	...	...	...	...	...	...	...	r					
Ctenacanthus	...	...	...	...	...	...	...	...	...	...	...	r	...	r	r	
Eukeraspis pustulifera, Ag.	...	...	...	...	...	...	...	...	...	...	c					
Hemiaspis	...	...	...	...	...	...	...	...	...	...	...	...	...	...	r	
Onchus Murchisoni, Ag.	...	...	...	...	...	c	...	c	...	...	...	r	...	c	C	r
O. tenuistriatus, Ag.	...	...	...	...	...	c	...	c	...	...	r	r	...	c	C	r
Thelodus parvidens	...	...	...	...	...	...	...	r								
Fish-spines	...	...	...	...	...	c	...	...	...	...	c					


Mocktree Hill
Hillpike
Woodhead
Cop Hall
Downton-on-the-Rock
Bow Bridge
Burri
RIVER TEME



[The map is oriented north and south.]


Geological Map
of the Neighbourhood of
LUDLOW.
Old Red Sandstones
Eurypterid-Shales
Yellow Sandstones
Chonetes-Flags
Rhynchonella-Flags
Dayia-Shales
Conchidium-Limestones
Alluvium
Scale:- 2 inches 1 mile
0
1/2
1
LUDLOW
Castle
Bridge
Ludford
10°
30°
50°
Steventon
RIVER TEME
Caynham Camp
Caynham
Caynham Court
Hucksbarn
Ashford House
Ledwych Brook
Park

EXPLANATION OF PLATE XXII.

Geological map of the neighbourhood of Ludlow, on the scale of 2 inches to the mile.

Discussion.

The President said that he was glad to see that, shortly after a paper had been read by one Cambridge student upon Sedgwick's classical area, other Cambridge students had devoted attention to the equally-classical region of Siluria. In each case, he understood that the authors accepted the broad lines drawn by the earlier workers, but gave more minute divisions than had been (in the former state of our knowledge) possible.

He congratulated the workers on the results that they had obtained, by means of groups of fossils which hitherto had not been extensively used in the stratigraphical classification of the Lower Palæozoic rocks of Britain. He felt that the Authoresses had established their classification for the region described. Whether it was applicable to wider areas remained to be seen, and he hoped that the Authoresses themselves would be able to establish this, for they had proved themselves eminently qualified for the task.

Prof. Hughes expressed his appreciation of the advantages which the Society now enjoyed, of hearing the results of the excellent work done by women in Geology from themselves and discussing the conclusions arrived at with them. Turning then to the subject-matter, he thought that the great interest of the paper lay in its being a careful examination of the lithological and palæontological characters of the deposits which were laid down at the close of the Silurian Period, when some great geographical changes were pending which brought the Silurian conditions to an end, and with no unconformity ushered in the Old Red Sandstone. This was quite different from the conditions which were found to have prevailed in North Wales and the North of England, where there was no Old Red of the Southern type, but the upturned edges of all the Silurian to the highest beds there seen were cut off and covered discordantly by the so-called 'Old Red,' which he considered to be the basement-bed of the Devonian or Carboniferous.

In answer to a question put by Dr. Teall, the speaker explained what he meant by the Northern and Southern type of Old Red, by means of a diagram sketched on the blackboard.

Mr. Hopkinson congratulated the Authoresses upon the excellent stratigraphical and palæontological work which their paper evinced. He had always considered that the *Monograptus-leintwardinensis* Beds formed the summit of the Lower Ludlow rocks, and had recorded (in 1872) one species of graptolite only, of wide range (*Monograptus colonus*), as occurring in the Aymestry Limestone, having found it in shale between the two beds of this limestone at Mocktree Quarry. If, as he understood, the Authoresses carried down the line of division between the Lower Ludlow rocks and the Aymestry Limestone to below the fissile flagstones of

Church-Hill Quarry, Leintwardine, *Monograptus leintwardinensis*, which there occurs in abundance, would now have to be regarded as the characteristic graptolite of the basal beds of the Aymestry Limestone.

Dr. A. SMITH WOODWARD expressed the hope that the Authoresses would extend their researches to the Llandovery area in the Cwm Dwr, where the section of Upper Ludlow and Lower Old Red Sandstone was particularly clear. He anticipated that the succession of faunas there would prove to be the same as that in the Ludlow district.

Miss ELLES, in reply, thanked the Fellows of the Society for their reception of her and Miss Slater's paper, and stated, in answer to Mr. Hopkinson, that they thought it advisable to consider the Leintwardine Flags as part of the Aymestry Limestone: since, wherever the limestone became less pure, the fauna characteristic of the Leintwardine Flags appeared.

11. *On the* Igneous *and* Associated Sedimentary Rocks *of* Llangynog (Caermarthenshire).

By Thomas Crosbee Cantrill, B.Sc. Lond., and Herbert Henry Thomas, M.A., B.Sc., F.G.S.[1] (Read January 24th, 1906.)

[Plates XXIII–XXVI.]

Contents.

I. Introduction.

In the neighbourhood of the village of Llangynog, some 6 miles south-west of the town of Caermarthen, an elevated tract of ground lying between the River Towy on the east and the Cywyn on the west, presents features of especial interest in that it contains several small masses of igneous rocks among the Ordovician sediments. In the re-mapping on the 6-inch scale of the South Wales Coalfield and the ground adjacent thereto, it fell to us to re-examine this district. In memoirs necessarily devoted chiefly to a description of the Coalfield, it is not possible to enter into such detail concerning the petrology and stratigraphy of these older rocks as they seem to deserve. We therefore sought the permission of the Director of the Geological Survey to lay before this Society the following particulars.

The district is comprised in the Old Series 1-inch Ordnance-map, Sheet 41; in the New Series 1-inch map, Sheet 229 (Caermarthen), and in the 6-inch maps, Caermarthenshire 38 S.E., 39 S.W., 45 N.E., and 46 N.W. It consists of an elevated plateau, which at Pen-y-Moelfre and Castell Cogan attains an altitude of 546 feet and 426 feet respectively; it is drained in part by several streams which flow southward into the estuaries of the Tâf and the Towy, and in part by streams flowing north-westward into the Cywyn, which itself falls into the Tâf.

[1] Communicated by permission of the Director of H.M. Geological Survey.

The south-eastern part of the plateau is occupied by the red marls of the Lower Old Red Sandstone, the base of which crosses the district from north-east to south-west, and rests with great unconformity on the various Ordovician and Cambrian rocks which make up the north-western part of the plateau.

II. Historical Summary.

The earliest references to the igneous rocks of the district appear to be the observations published by Murchison in 1839, in his 'Silurian System.' In chap. xxviii,[1] on Caermarthenshire, under the heading 'Trap of Castel cogan, &c.', he calls attention to the outburst of trap which occurs between the rivers Towy and Tâf, pointing out that the trap has been erupted along a north-east and south-west fissure, and is traceable at intervals for 3 or 4 miles, from Glog, past Capel [Bethesda] and Llangynog, to Castell Cogan and Gallt-y-minde on the left bank of the Tâf. He notices the felspathic character of the rock [rhyolite] at Gallt-y-minde[2] and Castell Cogan, and observes that it contains minute crystals of iron-pyrites. Having thus briefly noted the course of the supposed outburst, as followed from north-east to south-west, he retraces his steps and points out that, after subsiding for a while, the trap reappears at Capel [Bethesda] in the form of a concretionary felspar-rock [rhyolite]. He observes that the line of outburst is flanked by masses of volcanic grit, passing into a felspar-conglomerate [*Tetragraptus*-Grits]. At Glog this conglomerate had been deeply quarried, and the base of the quarries exposed

> 'a very hard rock, full of oblique rents and cracks, made up essentially of compact felspar, for the most part concretionary, whilst in the upper part, small pebbles of quartz become apparent, and are frequent near the summit. This felspar conglomerate, with quartz pebbles of the size of eggs, varies from that state to a grit, and when deeply laid open, consists of a concretionary and solid mass of felspar.'[3]

He points out that the strata along the line of eruption near Castell Cogan are extensively fractured; that the associated 'Silurian' grits are in places vertical and even inverted, and are unconformably covered by the Old Red Sandstone.

On his map Murchison shows four patches of 'trap' in the 'Silurian' rocks of the Llangynog district, and three patches of 'volcanic grit,' and notes the occurrence of 'trap-conglomerate.' Of his four patches of 'trap,' one is evidently the rhyolite of Castell Cogan; another, the rhyolite of Capel Bethesda; a third is presumably the mass of rhyolite which he appears to have seen in the deep quarry at Glog; while the fourth coincides in position with an elliptical outcrop of *Tetragraptus*-Grit at the old windmill

[1] Pp. 365–66.

[2] This name does not appear on the Ordnance-maps; Gallt-y-minde is the steep slope west of Castell Cogan.

[3] 'Silurian System' 1839, p. 365.

1 mile east of Llangynog village, but where no igneous rock is now to be seen. Strangely enough, the Lambstone porphyry is not represented on his map.

Of his three patches of 'volcanic grit,' one appears to be the *Didymograptus-bifidus* grit of Castell-y-garthen; a smaller patch to the north-east of this is probably a grit of like age, which crops out 400 yards west of Lambstone Farm; while the third is evidently the *Tetragraptus*-grit of Pen-y-Moelfre.

He represents the sedimentary rocks associated with the igneous rocks as 'Llandeilo Flags' and 'Upper Silurian' rocks: the 'Llandeilo Flags' are *Tetragraptus*-Beds (Arenig); the supposed 'Upper Silurian' rocks are certain green marls, cornstones, and sandstones, which form the basement-beds of the Old Red Sandstone of the district.

On his section (pl. xxxiv, fig. 11), which is drawn along a north-north-west and south-south-east line through Pen-y-Moelfre, Murchison represents the [Lower] Silurian rocks of that hill as undulating, not vertical, and as containing bands of volcanic grit; and a boss of trap is shown as bursting up between the Lower Silurian rocks, and what (from the colour on the map) he appears to have meant for Upper Silurian, but which are now known to be Old Red Sandstone. These supposed [Upper] Silurian rocks are represented as faulted off from the Old Red Sandstone. The last-mentioned boss of trap does not appear on the map, and does not indeed occur on the ground through which the section is drawn.

De la Beche[1] refers to the presence of conglomerates among the Lower Silurian [Ordovician] rocks of the district. The original Geological Survey-map, Sheet 41 (published in 1845), shows the igneous rocks at Coomb and Lambstone as ash-beds, but the rhyolite of Capel Bethesda is included in the diabase north of Pen-gelli-uchaf and coloured as a greenstone-dyke. The diabase of Tre-hyrn is not shown, and much of the ground occupied by andesites near that place is thrown into the sedimentary series.

The horizontal section, Sheet 2, Section 6, published by the Geological Survey in 1844, is drawn along a north-west and south-east line through Pen-y-Moelfre; it represents that hill and also Moelfre Wood as anticlines, with a syncline between them. The Lambstone igneous mass is shown as 'trap-rock,' and bleached shales are noted near the 'trap.'

The late Thomas Roberts[2] noted that 'the rock marked *Fs*b[2] on the Survey-map, near Llangynog, appears to be a diabase.' It is probable, although not certain, that in this passage he referred to the diabase of Tre-hyrn.

We have given a brief account of the igneous rocks in the 'Summary of Progress of the Geological Survey' for 1904.[3]

[1] 'On the Formation of the Rocks of South Wales & South-Western England' Mem. Geol. Surv. vol. i (1846) p. 29.

[2] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 170.

[3] Mem. Geol. Surv. 1905, p. 37.

III. The Sedimentary Rocks.

The sedimentary rocks associated with the various igneous masses consist of the following, in descending order:—

Lower Old Red Sandstone.	Red marls and sandstones; with a group of green marls and cornstones, sandstones, and conglomerates at the base.
Ordovician (Arenig).	*Didymograptus-bifidus* Beds.—Blue-black shales with one or more thick bands of grit (*Bifidus*-grits) towards the base. Graptolites of *D.-bifidus* type characteristic. *Tetragraptus*-Beds.—Black and buff shales, often iridescent and iron-stained, with interbedded thin grit-bands. Thick bands of ashy grit and conglomerate (*Tetragraptus*-grits) towards the base. Fossils rare; the shales yield extensiform and dendroid graptolites, *Tetragraptus*, and some horny brachiopods; *Didymograptus bifidus* is absent. The grits yield occasional specimens of *Orthis*.

(1) The *Tetragraptus*-Beds.

The beds belonging to this subdivision crop out on some elevated ground extending north-eastward from the village of Llangynog towards the River Towy, and occupy an area some 4 miles long by $1\frac{1}{2}$ broad. They are faulted on the north against an outcrop of *Didymograptus-bifidus* Beds, and on the south are bounded by the Old Red Sandstone. Stretching across the middle of this shale-area is a series of elliptical hills and ridges made up of grits and conglomerates. The ridges, which are frequently bounded on all sides by faults, are disposed in a zigzag line running from west to east, from Pen-y-Moelfre and Moelfre Wood, through the Windmill Hill, to Glog, a distance of 2 miles. Inasmuch as the grits and conglomerates forming these ridges are more or less vertical, the true order of succession is not obvious; but we have every reason to think that the grits and conglomerates are the same as those which form the core of a dome-like anticline at Bolahaul and Allt-cystanog south-east of Caermarthen,[1] where they underlie the equivalents of the *Tetragraptus*-shales and constitute the lowest member of the Arenig Series. At Llangynog they are again brought up in the form of anticlines, and are the oldest part of the *Tetragraptus*-Beds.

(*a*) Shales north of the Grits.

On the north of the grits the best sections are to be found along the upper parts of Nant Crymlyn, a stream which rises on some peaty ground north of the village of Llangynog, and flows north-westward to the Cywyn at Banc-y-felin. In this brook, due north of Lan-y-gors, greyish-black splintery shales and mudstones,

[1] 'Summary of Progress of the Geological Survey for 1904' Mem. Geol. Surv. 1905, pp. 33, 34.

with small horny brachiopods and dendroid graptolites, are exposed. The same beds have been cut through by the road from Forest to College, which here crosses the stream; and this section shows the iron-staining and iridescence that frequently distinguishes these beds. Traces of dendroid graptolites and horny brachiopods were found here, together with *Clonograptus* sp., as identified by Miss E. M. R. Wood.

There are other sections near College and about the village of Llangynog, and also at Lambstone Farm, in close contiguity to the Lambstone porphyry; for instance, in a cart-road leading to the fields behind Banc-y-ffynnon highly-micaceous buff shales dip west 10° north at 50° or thereabouts, towards the porphyry which crops out on some rough ground 50 yards farther to the west.

At Lambstone Farm, in a lane immediately west of a quarry in the porphyry, is a small opening in faulted and disturbed shales; there has evidently been some amount of movement between the shales and the porphyry, but the actual junction is not well-exposed. Small outcrops and débris of buff shales may be seen in the adjacent fields.

There are several outcrops of grit within the shale-area just described, but as they do not appear to lie on the horizon of the massive grits of Pen-y-Moelfre and Glog, and are relatively unimportant, they will not be further described. They can be seen at Ffordd and Nant-y-gôg; while another forms a low ridge running from Ffald south-westward towards Pen-y-Moelfre.

(*b*) The Grits and Conglomerates.

The main outcrop of grits and conglomerates first appears near Glog-ddu, nearly 2 miles east of Llangynog village. Here an elliptical outcrop of conglomerate forms a conspicuous ridge immediately west of the farm. The rock is exposed on a footpath at the eastern end of the ridge, and there are occasional outcrops along the crest; but the best section is afforded by a large and conspicuous old quarry on the northern face of the ridge. This is doubtless the quarry described by Murchison (*ante*, p. 224) as showing the conglomerate passing down into 'felspar-rock.' The only rock now visible is a conglomerate, consisting of well-rounded pebbles of what appears to be rotten rhyolite, with others of fine white quartzite, vein-quartz, and shale, embedded in a hard felspathic and sandy matrix, olive-green and buff in colour. The rock is devoid of bedding-planes; and such small evidence of bedding as is shown by the arrangement of the different-sized pebbles suggests a dip of about 20° to the north. There is no obvious difference between the beds at the top of the quarry-face and those at the foot. From Murchison's description we can only conclude that, at the time of his visit, some lower rock, now hidden, was exposed in the quarry, or that he was mistaken in his identification.

A quarter of a mile farther north the grits and conglomerates

reappear at Glog Farm, where they may be seen near the well a few yards north-east of the house. They consist of felsite-conglomerates and interbedded black shales which have yielded *Orthis*.

Traced westward from Glog, the grit-crop extends for about half a mile to the cross-roads north of Pen-gelli-uchaf. It is bounded on the south by a faulted strip of ground, which includes the rhyolites of Capel Bethesda, and a remarkable rhyolite-conglomerate of doubtful age. At the cross-roads is a quarry in rotten diabase, which appears to have been intruded into the grits.

The bare surface of the road about 60 yards north of the cross-roads shows pebbly grits, largely made up of rhyolite, within a few feet of the diabase which is exposed on the road-surface and also in the old quarry hard by. The grit-outcrop can be followed from this point as far as the site of Lan-ganol, 120 yards south of which a small quarry by the side of a field-road shows, within a few feet of the conglomerate, black, yellow-weathering shales. These yielded *Dictyonema* sp. and *Orthis Actoniæ (?)* Sow., and appear to be identical with the shales which immediately succeed the conglomeratic grits in the Caermarthen district.

At Lan-ganol the grit-outcrop abruptly turns back on itself, and trends in a west-south-westerly direction. At Pen-y-graig Farm it forms a prominent elliptical hill, on the north side of which a roadside-quarry, 80 yards west of a ruined windmill, exhibits massive pebbly grit apparently dipping northward at 70°. It has already been pointed out (*ante*, p. 224) that Murchison's map represents a patch of trap somewhere hereabouts, but we have not been able to find any such rock.

South-west of this quarry are several exposures of the grits and conglomerates in the roads, by which the outcrop can be traced to Ffald. Here it appears suddenly to terminate against a north-east and south-west fault, which introduces an outcrop of higher non-conglomeratic grit.

The conglomeratic grits reappear, however, in Pen-y-Moelfre. This hill consists of an elliptical mass of grits and conglomerates; it seems to be faulted on all sides, except on the west-north-west, where the grits appear to pass up into shales. It presents good sections by the roadside south of Llangynog School, and a few yards farther south at some roadstone-quarries, where the beds are vertical.

At the southern end of the hill, about a quarter of a mile farther to the south-east, a large quarry near Llangynog Vicarage shows coarse buff sandstone, with frequent pebbles and some shale-partings; the grits have yielded *Orthis*. Here it is very evident that they are cut off on the south by a fault, for they strike directly towards a good section of fine-grained olive-green shales and sandstones, much disturbed and contorted, at the Vicarage-gates.

East of this section the grits make up the lofty hill of Moelfre Wood, and are exposed in the road at Moelfre Gate. The hill ends in a bold north-and-south scarp a little west of Moelfre Farm, and,

as sandy-shale débris appears at the foot of the slope, the grits evidently extend no farther eastward. The shales themselves, however, are immediately cut off by a north-and-south fault, which introduces the green basement-conglomerates of the Old Red Sandstone of Moelfre Farm.

(*c*) Shales south of the Grits.

Reverting now to the eastern part of the district, we find olive-green shales cropping out in a lane at the western end of the grit-ridge of Glog-ddu; but west of this point they are concealed by boulder-clay, although they doubtless occupy the low ground north of Pen-gelli-uchaf. They have been quarried on the east side of Pen-y-coed Brook, halfway between Waun-dâs and Craig. Thence they extend over the low ground south of Ffald, and can be seen at Ffynnon-wen immediately north of the edge of the Old Red basement-beds. South of this Old Red tract, they are poorly exposed in Pen-y-coed Brook, 300 yards west of Waun-dâs, and consist of highly-micaceous soft shales, with thin bands of hard grit. Grey micaceous shales are to be seen at the junction of three roads half-a-mile east-north-east of Llangynog Church.

In the road by Llangynog Church, and thence southward to Llangynog Farm, there is a development of thin grits in the shales; and shales with thin grit-bands are exposed occasionally in the road between the Church and the Plough-&-Harrow Inn.

West and south of this, the *Tetragraptus*-Beds are faulted off from the *Didymograptus-bifidus* Beds of Gardd-erfin and the andesites of the Coomb complex.

(2) The *Didymograptus-bifidus* Beds.

These occupy the ground to the north, west, and south-west of the *Tetragraptus*-Beds described above, and are everywhere faulted off from them. In the neighbourhood of Llangynog they exist as an inverted series, excellently exposed in the middle part of Cwm Crymlyn, where, although the *Tetragraptus*-Beds appear to pass normally under them, there is in reality a fault of considerable magnitude which throws the higher beds of the *Didymograptus-bifidus* shales against the *Tetragraptus*-Beds.[1] In the dingle, the typical characters of the shales may be observed, and specimens of graptolites of the *D.-bifidus* type collected.

A thick band of grit crosses the dingle, and can be followed south-westward past Uchel-ole to a large old quarry on the north of a ravine at Eithin-duon, where it is cut off by a north-westerly fault which runs down the dingle. The grit reappears one-third of a mile farther south, on the western side of the Lambstone porphyry-hill. The grit is followed on the north-west by shales which extend down to the Cywyn Valley. These are to be seen in

[1] 'Summary of Progress of the Geological Survey for 1904' Mem. Geol. Surv. 1905, p. 47.

several small exposures, and have yielded graptolites of the *D.-bifidus* type; while, south-east of the grit, shales may be seen in the road bordering the western side of the Lambstone porphyry, against which they are faulted: these have yielded similar graptolites.

South-west of Lambstone Farm these shales extend towards Llandeilo-Abercowin; the grits form the northern slopes of the hill (crowned by an old camp named 'Castle' on the 6-inch map) west of Gardd-erfin; and shales in a cart-road 200 yards west of that farm have yielded Dichograptid stipes, a small *Diplograptus* or *Climacograptus*, and a form of the *Didymograptus-bifidus* type. South of this section they are exposed in a brook, in which, at a point 350 yards north-west of Gelli, they have yielded specimens of *Didymograptus* of the *bifidus*-type, *Diplograptus dentatus (?)* Brongn., and *Didymograptus* cf. *stabilis*, Elles & Wood, together with *Trinucleus*, sp. nov. (?), and *Ampyx nudus (?)* Murch.

They are faulted against the igneous rocks of the Coomb complex, from the Coomb dingle on the north-east, by Gelli, to Pentre-newydd on the south-west. At Gelli they contain grits, and in a lane 150 yards south-west of the farm they have afforded *Didymograptus bifidus*, Hall, and *D. artus*, Elles & Wood, within a yard or two of the andesites. At Pentre-newydd, some included grits are exposed in the yard by the side of the house. These and the grits at Gelli are probably on the horizon of the chief band, which is to be found some 250 feet above the base of the subdivision in other parts of the district.

South-west of Pentre-newydd the shales are well-exposed, although somewhat weathered and contorted, in a road-cutting west of the Cross Roads, and have yielded graptolites of the *Didymograptus-bifidus* type and *D. Murchisoni (?)*, together with *Æglina* sp., *Ampyx nudus*, Murch., *Ampyx* sp., *Barrandia Cordai*, M'Coy, and *Barrandia* sp.

Immediately south of this section they are unconformably overlain by the basement-beds of the Old Red Sandstone, and faulted on the south-west against the Bala Limestone and *Dicranograptus*-Shales of Llandeilo-Abercowin.

(3) The Old Red Sandstone.

The lowest beds of the Old Red Sandstone are a group of sage-green and buff, rocky, calcareous marls and cornstones, with some interbedded conglomerates and micaceous green sandstones. They form a well-marked basement-group to the red marls of the Lower Old Red Sandstone of the district.

(*a*) The Main Outcrop.

At the eastern end of the area they are poorly exposed in Fernhill Brook at Rhyd-lydan, where they strike towards the *Tetragraptus*-Beds of Glog, and are presumably separated therefrom by a fault running along the brook. This fault bends westward along

the south side of Glog-ddu hill, where it apparently cuts out the green beds and brings the red marls against the *Tetragraptus*-conglomerates, although the former are buried under drift.

At Pen-gelli-uchaf the green beds reappear, and are well-exposed in the fields between that place, Waun-dâs, and Pen-y-coed. They contain numerous beds of hard rocky marl full of pebbles (ranging up to an inch or so in length) of rhyolite derived probably from the igneous masses of the district. Instead of dipping south-eastward towards the succeeding red marls, they dip about north-north-west, and apparently overlie the red marls. They must, therefore, be either inverted or faulted-off from the red marls on the south.

They are faulted on the north and west against *Tetragraptus*-Beds; and, for some distance in the direction of Coomb, appear to be inverted, as they dip north-westward towards the *Tetragraptus*-Beds.

North of Coomb the base of these green beds leaves the fault by which they are separated from the *Tetragraptus*-Beds on the north, and can be traced with complete precision along the eastern side of the Coomb dingle, crossing the successive outcrops of the andesites and rhyolites of the Coomb complex; while, on the western side of the dingle, the lowest bed, a rhyolite-conglomerate, 10 feet thick, can be seen dipping at 60° from the rhyolites along the southern side of Castell Cogan.

At Pentre-newydd the green beds pass from the igneous rocks onto the *Didymograptus-bifidus* Beds, and the junction may be examined in the road west of the Cross Roads.

(*b*) Detached Areas.

Between Waun-dâs and Moelfre a small area of the basal green beds has been thrown-in to the north of the main outcrop; it is faulted on all sides, except on the north. The beds consist of green and buff marls and highly-micaceous sandstones, with occasional bands of rhyolite-conglomerate. The green marls and sandstones are best seen in Pen-y-coed Brook 300 yards north-north-west of Waun-dâs, and dip south-south-eastward at 25°; from beneath them rise lower beds, which contain conglomerates visible in the fields to the north. The conglomerates are, however, still better exposed at Ffynnon-wen, and also at Moelfre, where they strike nearly due east and west with a high dip, and contain large pebbles of a felsitic rock.

One other, though somewhat doubtful, patch of these basal beds remains to be described. On the southern edge of a low gorse-covered ridge, a small roadside-quarry 80 yards west of Capel Bethesda exposes some 8 feet of a very coarse conglomerate, made up of well-rounded pebbles and boulders (ranging up to about a foot in diameter) of white rhyolite, among which a few small pebbles of vein-quartz and fine white quartzite are present. The upper part of the section is much weathered, and there is very little matrix; in the floor of the quarry the rock is more coherent.

We are uncertain whether to refer this conglomerate to the green

beds of the Old Red Sandstone or to the *Tetragraptus*-Grits; the coarseness of the material, however, compared with that of the *Tetragraptus*-conglomerate of Glog-ddu Hill (500 yards to the south-east) has alone determined us to group it provisionally with the Old Red Sandstone. Some 50 or 60 yards north-west of the quarry, and on the top of the ridge towards its western end, one or two angular masses of white-weathering rhyolite project through the soil. These do not appear to belong to the conglomerate; and if they are not blocks, ice-borne from the exposure of that rock at the Chapel, they must be the top of a rhyolite-mass projecting through the conglomerate. The rhyolite at the Chapel is striated west 22° south, a direction which points towards the possible boulders.

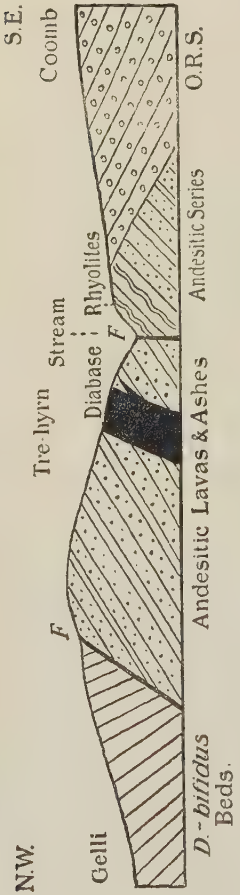


Fig. 1.—*Section across Coomb Dingle, on the scale of 6 inches to the mile.*

IV. The Igneous Rocks.

The igneous rocks of the Llangynog district occur in three well-defined areas which, taken according to their importance, are (1) near Coomb; (2) at Capel Bethesda; and (3) at Lambstone.

(1) The Rocks near Coomb.

The igneous rocks in the neighbourhood of Coomb occupy an area of about half a square mile, and are bounded on the south and east by the Old Red Sandstone, which unconformably overlies them; while on the north and west they are faulted against *Tetragraptus*-Beds and *Didymograptus-bifidus* Beds. This area of igneous rocks is naturally divided into two unequal portions by a dingle through which a stream flows southward from near the Plough-&-Harrow Inn, past Llwyn-celyn, and ultimately falls into the estuary of the Tâf. This dingle will hereafter be referred to as 'the Coomb Dingle.'

On the eastern side of the dingle, the rocks consist of two series of andesites and associated tuffs, separated by a mass of rhyolites and rhyolitic breccia. On the western side, to the north, occurs a series of andesites into which the diabase of Tre-hyrn has been intruded, and to the south lies the large mass of rhyolitic rocks of Castell Cogan. A small patch of intrusive diabase appears at the extreme south-west of the area, near Pentre-newydd.

(a) The Eastern Side of the Dingle.

(i) The Lower Andesitic Series.—In the main road, at a point about 300 yards north-west of Coomb House, these rocks may be seen to emerge from below the Old Red Sandstone and to dip northward at 52°, and, on the side of the dingle, north 20° west at 45°, and may be followed upward and northward for about 200 yards. They consist largely of banded tuffs, with occasional vesicular and fine-grained-andesitic lavas, which are well-exposed on the steep slope between the main road and the stream to the west. Good vesicular rocks and more compact lavas may be seen to the west of the bend which the road takes before it reaches the Old Red rocks. This volcanic series nowhere exhibits its lower limit, but the calculated thickness of the rocks seen is at least 350 feet.

(ii) The Rhyolites.—Succeeding the above is a series of rhyolites from 140 to 150 feet thick, consisting of pale-yellow, grey, or white-weathering rocks, often minutely but markedly spherulitic even in the hand-specimen. These rocks follow the dip and strike of the andesites below and succeed them with absolute conformity. The highest bed consists of a beautiful rhyolitic breccia, made up of fragments which range up to an inch or more in length, and are similar in all respects to the rhyolites below. This breccia forms a well-marked feature, and a series of crags, running from the main road, down the slope, to the stream; it is easily located, as it is almost due east of Tre-hyrn farmhouse.

(iii) The Upper Andesitic Series.—Immediately above the breccia which forms the summit of the rhyolites comes a series of andesitic tuffs and lavas, with an estimated thickness of about 900 feet, and identical in appearance with those of the lower series. These beds are best seen in the wood running alongside and above the road, and are exposed from the rhyolites northward to beyond Llwyn-celyn. The first exposure occurs immediately above the breccia, and is seen to consist of a fine-grained, compact, green tuff. The road-bank and the wood to the east, between the breccia and the tributary stream which flows into the dingle at Llwyn-celyn, are occupied by banded tuffs and lavas, chiefly vesicular. The beds dip northward at from 40° to 50°, and the section seen along the road and in the wood, from the limiting-fault on the north to the rhyolitic breccia on the south, is as follows, in descending order:—

	Thickness in feet.
Banded tuffs	90
Compact tuffs and andesite	20
Banded tuffs	65
Tuffs and obscure ground	195
Banded tuffs	105
[Tributary stream at Llwyn-celyn.]	
Banded tuffs	70
Vesicular andesite	7

(Section continued.)	*Thickness in feet.*
Tuffs	20
Compact andesite and tuffs	20
Fine-grained vesicular andesite	6
Tuffs	35
Thin vesicular andesite	3
Tuffs	10
Thin vesicular andesite and tuffs	173
Rhyolitic breccia.	

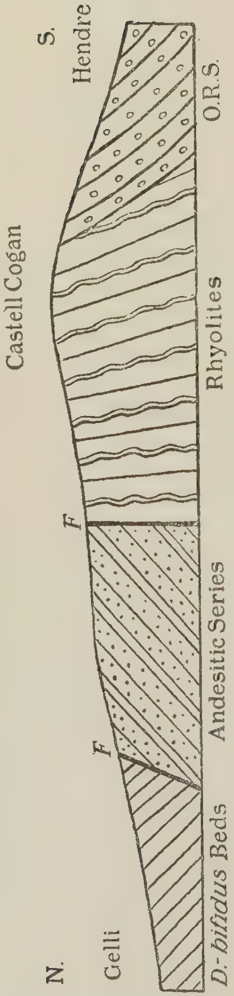


Fig. 2.—*Section across Castell Cogan, on the scale of 6 inches to the mile.*

In the above series six flows have been identified; but, owing to some of the ground being obscure, it is impossible to say whether any more are present in the section.

(*b*) The Western Side of the Dingle.

(i) The Rhyolites of Castell Cogan.—The rhyolites of this area are faulted off from those on the eastern side of Coomb Dingle, and form the high ground to the south of Tre-hyrn. The country rises rapidly from the stream-level (100 feet above Ordnance-datum) to the rampart of the ancient camp of Cogan, at a height of 426 feet. It then gradually falls again towards Pentre-newydd, to an altitude of 200 feet. The rhyolites are pale-yellow and grey rocks weathering white, which locally show good spherulitic and fluxion-structures.

Although the area occupied by these rocks is considerable and débris of them is plentiful, outcrops of solid rock are not numerous; exposures may be seen to the best advantage, midway between the camp and the dingle, at a point situated at the top of the wood; and also about 200 yards west of the road near the junction with the andesites. At the top of the wood, the rocks dip south-eastward at 60° to 80°, while at the last-named exposure they are vertical and strike west 30° south.

The exposures and dips of these beds, provided that there has been no strike-faulting, would indicate a thickness of rock of in all probability not less than 1150 feet.

(ii) The Andesitic Series.—North of the rhyolites of Castell Cogan, and probably faulted from them, is a series of some

900 feet of andesitic rocks, which, generally speaking, occupies a less elevated tract of country. The best exposures of these rocks are situated on the western side of the Coomb Dingle, east and north-east of Tre-hyrn Farm, where the beds, which consist chiefly of olive-green banded tuffs, are well seen along and near the footpath leading from Tre-hyrn to Llwyn-celyn. These tuffs undulate considerably in strike, but have a general dip of 35° to 45° in a north-westerly direction.

Surmounting the slope occupied by these tuffs, and forming conspicuous crags west of Llwyn-celyn, is a pale massive rock, probably of extrusive character, which microscopical examination has shown to have the composition of a hornblende-andesite. Its lower limit is exposed along the side of the dingle for some distance, but its summit is nowhere seen; however, there is sufficient evidence to prove that it is followed by another series of tuffs similar to that which preceded it. There are very few exposures of the andesitic rocks on the west towards Gelli, and such as there are evidently consist of the usual types of banded and pumiceous tuffs.

(iii) The Diabase of Tre-hyrn.—This rock is intruded into the andesitic tuffs below the hornblende-andesite, and in character varies from a dark-green, finely-crystalline rock to a more compact variety, which is hard to distinguish in the hand-specimen from some of the andesitic tuffs. The rock is well-exposed south-east of Tre-hyrn farmhouse, and occupies the footpath for about 50 yards in the direction of Llwyn-celyn; it may then be traced along the bank for another hundred yards to the north-east. At this point the intrusion breaks across the andesitic tuffs, and continues its course as a much thinner sheet at a higher horizon, tailing off to a band a few feet thick, and occupying a position on the side of the dingle midway between the hornblende-andesite and Llwyn-celyn. Its maximum thickness is exposed at Tre-hyrn.

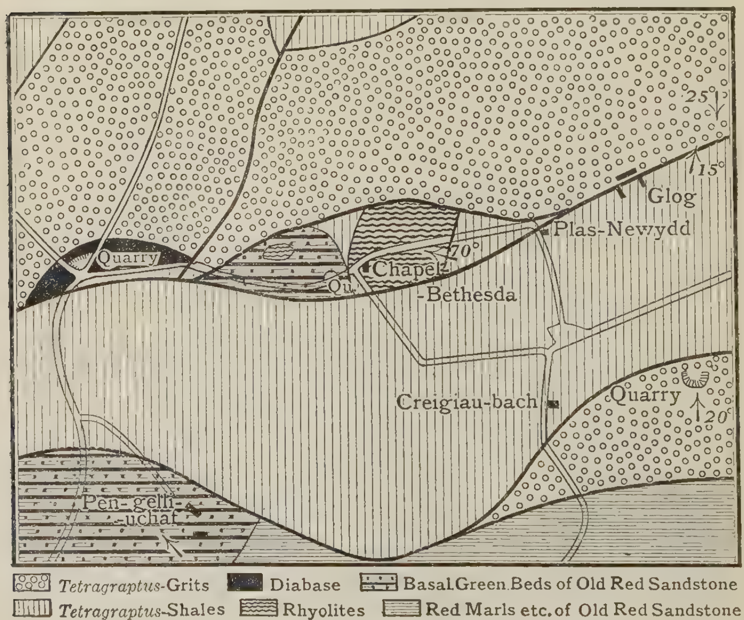
(iv) The Diabase of Pentre-newydd.—This rock is exposed only in the road east of Pentre-newydd, appearing on the immediate north of the Old Red Sandstone and merely a few feet away from its base.

Passing northward up the hill to a gate at a bend in the road, in a distance of 30 yards, the section is seen to be as follows:—The most southerly exposure consists of a pale-blue rock with conspicuous pyrites-crystals; the rock is very much decomposed, but has a parallel structure which strikes about south 25° east. A little higher in the road the mass becomes much fresher in character, and lath-shaped felspars, small patches of chlorite, and crystals of pyrites may be detected in the hand-specimen. This is succeeded by a dark-greenish-grey rock with lath-shaped felspars, and that by a more compact marly looking rock, which northward gives place to the blue variety first mentioned. Just at the bend of the road, the section is occupied by sedimentary rocks, consisting of grits with fairly-large grains of opalescent quartz, and a few thin beds of badly-weathered greenish shales. The section continues from the bend

in the road northward, both in the road and in the hedgebanks for a distance of 17 yards. The hedgebank shows a section, in what looks like a more basic variety of the diabase, and this type continues up to the junction of the intrusive rock with the rhyolites, which may be located to within a few inches. At the junction the diabase is exceedingly rotten, and has been sheared against the harder rhyolites. The rhyolite at the junction has a flinty margin without spherulites, but is immediately succeeded by a beautifully-spherulitic rock. The mass of sediments in the section is either a patch caught up in the intrusive rock, or a bed lying between two tongues of diabase. These sediments, however, present no recognizable signs of metamorphism.

Although no other exposures of solid rock are seen, from the loose pieces of diabase scattered through the soil of the tract between the road and Pentre-newydd Farm, it would appear that this area also is occupied by the intrusive rock.

Fig. 3.—*Geological map of the country around Capel Bethesda, on the scale of 6 inches to the mile.*



(2) The Rocks at Capel Bethesda.

The igneous rocks in the neighbourhood of Capel Bethesda occupy a narrow strip of country, following the road from Glog to the four cross-ways north of Pen-gelli-uchaf. The rocks consist of rhyolites and a rotten diabase.

(*a*) The Rhyolites.—The rhyolitic rocks are best exposed in the road immediately to the east of Capel Bethesda, where they dip a little north of west at 70°. They are tough blue-grey rocks which weather white, and contain small but conspicuous cubes of pyrites: occasionally they are markedly spherulitic. They are bounded on the north by a fault, which separates them from the *Tetragraptus*-grits; and on the south, although the ground is much obscured by drift, there is every reason to think that they are again faulted off from the main mass of Arenig sediments. The estimated thickness of rock seen is certainly more than 400 feet: and if, as seems probable, these rhyolites extend westward under the conglomerate in the roadside-quarry mentioned on p. 231, then the thickness would have to be greatly increased.

(*b*) The Diabase.—At the cross-roads north of Pen-gelli-uchaf, in an angle between two of the roads, is an old disused quarry opened up in a very rotten, basic, igneous rock. The mass is full of joints and cracks, and veined with calcite. On the surface of the road to the east of the quarry the rock is well-exposed, but is quite as rotten as before; it has a bluish colour, and contains fairly-large patches of calcite, which give it almost an amygdaloidal appearance.

The road-section is about 60 yards in length, and is seen to include a thin mass of sedimentary material in the form of greenish indurated (? ashy) shales. These sediments may also be seen in the northern hedgebank of the road to Glog, at 20 yards from the cross-ways. Immediately north of these last-mentioned shales is a steep furze-covered bank, in which by far the freshest diabase is exposed. The intrusion is bounded on its northern side by grits and shales of *Tetragraptus*-age, but the junction between the two series of rocks is nowhere exposed.

(3) The Lambstone Porphyry.

The mass of igneous rock at Lambstone occupies a position due west of the village of Llangynog [Llangunnock], and forms an elliptical hill to the north of Lambstone Farm, nearly half a mile long and one-sixth of a mile wide. The boundary between the igneous rock and the surrounding sediments is marked by a strong feature, which is easily traceable all round the hill. The mass is faulted on its western and southern sides, but on the north and east the junction seems to be a normal one. On the west it is faulted against black shales containing graptolites of the *Didymograptus-bifidus* type; while, on the south, these give place to yellow, splintery, and possibly-indurated shales belonging to the lower part of the *Tetragraptus*-series. In the neighbourhood of Lambstone Farm, the junction (which is still a fault) may be closely located, the shales striking almost at right-angles to the igneous mass.

On the eastern and northern sides of the hill the junction seems to be an unfaulted one, for the shales strike parallel to the boundary

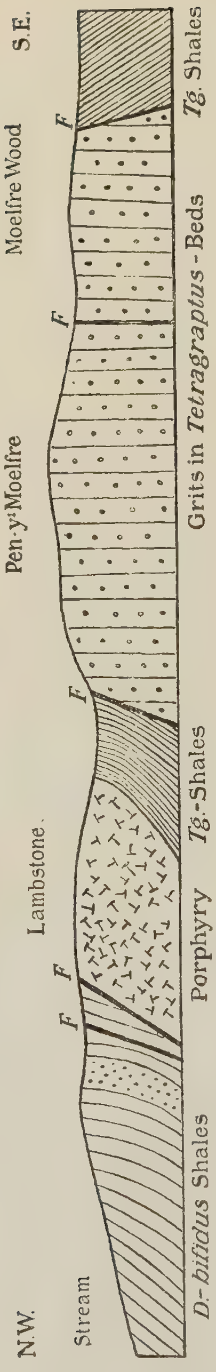


Fig. 4.—*Section across Pen-y-Moelfre, on the scale of 6 inches to the mile.*

of the igneous rock and appear to pass below it. The way in which the shales curve round the northern end, and dip towards the igneous mass, would suggest that the porphyry is a sill-like mass resting within a syncline in the *Tetragraptus*-shales.

In hand-specimens, the rock is of a pale-blue colour, and weathers grey and white. There are many exposures of the weathered rock, in the form of crags, all over the hill and on the slopes; but by far the freshest rock is to be seen in a small road-metal quarry immediately north-west of Lambstone Farm.

The mass has an estimated thickness of several hundred feet. From the microscopic characters of this rock, the absence of flow-structure, its massive jointed appearance, and the seeming induration of some of the surrounding sediments, we conclude that it is of intrusive nature.

(4) Detailed Petrography.

1. The Coomb Rocks.

(*a*) The Lower and Upper Andesites of the Eastern Side of the Dingle.

As there are no petrographical differences to distinguish the rocks which occur above and below the rhyolites on the eastern side of the Coomb Dingle, they may be conveniently considered together.

i) The Flows.—Specimens were collected and slices cut from well-marked flows—one [E 4137–38–39[1]] 90 yards south of the lower limit of the rhyolites, and another [E 4130] 25 yards south of the eastern tributary stream which flows into the dingle at Llwyn-celyn. In hand-specimens they are seen to consist of coarsely-vesicular rocks of a bluish-green colour, weathering brown.

[1] The numerals in square brackets throughout this paper refer to the registered numbers of the slides in the Geological Survey-Collection.

The vesicles are filled with a soft mineral, which appears darker than the surrounding rock. These highly-vesicular flows have a mean specific gravity of 2·70.

Under the microscope the rocks are seen to be vesicular hyalopilitic andesites, with soda-lime felspar abundantly developed and occurring in two generations. The felspar of the first generation builds lath-shaped crystals, unzoned, but usually twinned according to the Carlsbad and albite-laws. Pericline-twinning is not common, but interpenetration-twins and stellate groups are of frequent occurrence. The felspars are, as a rule, fairly fresh; but occasionally they show a development of secondary quartz, pale-green chlorite, and dusty material of a micaceous character. The series of low symmetrical extinctions on the twin lamellæ, and on sections at right-angles to the acute bisectrix, would indicate that the majority of these felspars lie in composition between oligoclase and andesine. The second generation of felspars consists essentially of microliths with low or almost straight extinction, indicative of oligoclase, arranged in bunches and fan-like aggregates which make up the bulk of the groundmass of the rock, and cause it to present almost a variolitic appearance.

No original ferromagnesian mineral in the unaltered state now exists in these rocks, but undoubted pseudomorphs after augite occur plentifully, showing the external form in many cases (see Pl. XXV, fig. 1). The interior of these pseudomorphs is composed of a mosaic of secondary quartz and chlorite. Felspar-laths may be seen to penetrate the augite, and we therefore infer that the ferromagnesian mineral was of a later consolidation than the first generation of felspars.

The vesicles, which range up to ·2 inch in diameter, are either spherical or irregular in shape, and are filled with fibrous chlorite-minerals in radiating masses, either alone or with a little calcite or secondary quartz. Many of the larger vesicles are lined with a thin layer of secondary quartz, ·02 to ·04 mm. thick. The groundmass, although largely composed of felspar-microliths, contained a small quantity of interstitial glass, now more or less completely devitrified and clouded with iron-ores. The chlorites filling the vesicles are of two varieties: the commonest is pale-green, feebly pleochroic, building fibrous and (less frequently) scaly aggregates. The zone of elongation of the fibres has a positive sign, and the mineral has a low double refraction ($\gamma - \alpha = \cdot 005$).

The other mineral, which is sometimes intergrown with the former, has a deeper colour and stronger pleochroism, but occurs in fibrous aggregates. The maximum absorption is for light vibrating parallel to the length of the fibres, of which the zone of elongation is positive. For light vibrating parallel to the long axis of the fibres, the absorption gives a yellowish-brown, and for a direction at right-angles thereto yellowish-green. In a slide a little more than ·03 mm. thick, the mineral gives the yellow and red polarization-tints of the first order, which would indicate a birefringence of from ·014 to ·015. From the foregoing considerations, we are led to regard the mineral as one of those to which the name delessite

has been applied, more or less common in the amygdules of ancient rocks which carry ferromagnesian minerals.

Another variety of andesitic rock [E 4439] was observed to form a thin band, only 8 feet thick. It is of a dark-green colour and fine-grained texture, and occurs in the upper andesitic series 80 yards north of Llwyn-celyn. This rock has a specific gravity of 2·65. Under the microscope, it is seen to consist almost entirely of a mass of minute lath-shaped felspars and microliths, with little or no interstitial material, while porphyritic crystals of any kind are practically absent.

Augite probably existed as granules, and its presence may be inferred from the small chloritic grains which occur between the felspars. The felspars are twinned usually but once, although occasionally they show albite-lamellation. The symmetrical extinctions range from 0° to 5° on either side of the twin-plane, indicating oligoclase as the species to which the felspars belong, and showing that these microliths correspond more or less exactly with those occurring in the more coarsely-crystalline andesites described above. This rock may be said to have a typical pilotaxitic structure (Pl. XXV, fig. 2). It is but feebly vesicular, for a very few small vesicles occur, which are filled in the usual manner with pale-green chlorite in fibrous aggregates. The felspar-microliths show an arrangement that roughly approximates to parallelism, indicating in a measure the direction of flow, but many of the crystals are curved or broken; and from this, taken in conjunction with the comparative irregularity of their arrangement, it would appear that the rock must have been in a fairly-viscous condition immediately prior to its consolidation. Only a very few crystals of a porphyritic character occur, and the biggest, an oligoclase-andesine felspar, measured ·7 by ·5 mm. The felspars were partly decomposed, with the formation of epidote.

A specimen taken from the surface of a flow in the lower andesites, at a point a little below the rhyolites, proved to be a fluxion-breccia. The rock is made up entirely of andesitic material, mostly pumiceous, with a flow-structure developed between the fragments. These fragments are identical, in every respect, with those occurring in the pumiceous tuffs described on p. 241.

(ii) The Fragmental Rocks.—The fragmental rocks of andesitic character are largely in excess of the flows, and usually are fine-grained, well-banded rocks of a buff to yellowish-green colour. Many samples were collected from the lower and upper andesites; under the microscope they were seen to consist of alternating coarser and finer bands of sedimentary material, and to be composed of angular grains and fragments of quartz and felspars. The larger fragments are set in a finer matrix of felspar-microliths and broken felspar-crystals.

There is little doubt that, in these rocks, there is a considerable proportion of clastic material, and it is uncertain whether they should be classed as true ashes rather than as ashy sediments.

The pumiceous tuffs are not of any great thickness, when compared with the banded rocks described above, but they occur, and present exactly similar characters, in both the lower and the upper andesitic series. They consist of lapilli of pumiceous and hyalopilitic andesite, of which the vesicles are filled with a pale-green chlorite (Pl. XXVI, fig. 1). The fragments are set in a fine-grained matrix, made up almost entirely of broken felspar-laths and microliths, with a certain amount of chlorite and a few clastic quartz-grains. The felspars in the lapilli are usually all oligoclase-microliths; but occasionally some of the larger fragments may contain small lath-shaped crystals of a slightly more basic variety.

(*b*) The Rhyolites on the Eastern Side of the Dingle.

The rhyolites on the eastern side of the dingle are pale, highly-silicified rocks. They present both perlitic and spherulitic structures. A specimen collected from a small quarry above the main road [E 4143] proved to be a beautifully-spherulitic rhyolite (Pl. XXIV, fig. 1). The few phenocrysts that occur are felspars of the albite-anorthite series; they are twinned according to the Carlsbad and albite-laws, and give low symmetrical extinctions indicative of a fairly-acid oligoclase. Subordinate orthoclase also occurs. These phenocrysts range up to 1·3 mm. in length, and are set in a groundmass which was once glassy but is now completely devitrified. The matrix consists of cryptocrystalline quartz and felspar, but in parts of the slide traces of the original flow-lines and a perlitic structure may still be made out.

The spherules, which are abundant, and are often observed to coalesce, average 0·4 mm. in diameter; they are well-bounded, and in ordinary light appear more transparent than the rest of the rock. They are composed of radiating and branching felspar-fibres, of which the zone of elongation has a negative sign, and giving practically-straight extinction. Between crossed nicols the spherulites show a well-defined cross at the centre, which becomes blurred and indistinct outwards towards the margin, owing to the branching and change of direction of the felspar-fibres.

It appears that these spherulites are a direct result of the devitrification of the rock, as they occur as the nuclei of the perlitic structure. A very few minute patches of fibrous brightly-polarizing chlorite (p. 239) occur in the groundmass, and may perhaps represent vesicles; while others, of a chlorite with lower birefringence, may possibly represent some ferromagnesian mineral.

(*c*) The Rhyolitic Breccia.

This rock seems to be a true fluxion-breccia, and consists of fragments of perlitic and spherulitic rhyolites set in a matrix of

similar material, which occasionally shows a well-defined flow-structure.

A section cut from one of the larger fragments showed it to be a devitrified patchy rhyolite [E 4144], with a pseudospherulitic structure. The phenocrysts consist of oligoclase and oligoclase-andesine felspars, both considerably decomposed, set in a felsitic groundmass which has suffered more or less complete recrystallization both of the felspar and the silica. The secondary felspar is usually clear and granular, but the slide also shows one fairly-large spherule.

Another section [E 4146] shows a devitrified perlitic rhyolite, with included fragments of a hyalopilitic andesite caught up in it and seemingly in part absorbed. The rhyolite has a well-marked flow-structure in places, and locally becomes perlitic, or less frequently spherulitic. The fragments of andesite consist of masses of felspar-microliths with some interstitial material, while the rhyolite often exhibits good flow-structure around these xenoliths.

Two sections [E 4438 & 4443] cut from the rhyolitic breccia at the point where it crosses the road, show patches of rhyolite with perlitic structure. This structure occurs chiefly in those patches which have either escaped devitrification, or in which the reconstruction has proceeded to no great extent. The still glassy part of these rhyolite-fragments is usually stained a pale-yellow colour, and may be distinguished by this character in the hand-specimen. A good example of a perlitic fragment from this breccia [E 4443, specific gravity 2·69] is figured in Pl. XXIV, fig. 2.

(*d*) The Rhyolites of Castell Cogan.

These rhyolites are similar in many respects to those on the eastern side of the dingle, both in the hand-specimen and under the microscope. They have a mean specific gravity of 2·54.

Slices cut from several localities [E 4140, 4141, 4159] showed almost entirely-devitrified rocks, in which little or no trace of original structures could be identified. The phenocrysts, which are by no means common, consist of fairly-large felspars, measuring as much as 3 mm. in length, all but completely converted into sericitic decomposition-products. They show traces of Carlsbad twinning, and the crystals apparently have the sanidine-habit.

Well-formed quartz-crystals (·3 mm. in length) occur: these are in all probability of secondary origin, although they are surrounded by a zone of cryptocrystalline material, which seems to pass gradually into their peripheries.

The groundmass is completely devitrified in all cases, and usually has a cryptocrystalline character; occasionally, however, it becomes somewhat coarse, and presents a patchy appearance, due to the secondary crystallization of both the felspar and the quartz. Generally speaking, no other structures are present; but occasionally it is possible to make out the original flow-lines, and in places the rocks become spherulitic.

The best example of a spherulitic rock collected from this series of rhyolites was taken from the road-section close to, and a little north of, the junction of the rhyolites with the Pentre-newydd diabase.

(*e*) The Andesites on the Western Side of the Dingle.

The andesites on the western side of Coomb Dingle may be divided into two groups, one consisting of augite-andesites, and the other of hornblende-andesites.

The group of augite-andesites, both as regards the flows and the fragmental rocks, is petrographically identical with the upper and lower andesitic series on the eastern side of the dingle, already described (pp. 238 *et seqq.*).

A rock exposed in the road, 320 yards west-south-west of Tre-hyrn [E 4151], is seen to be a coarse tuff, made up largely of fragments of vesicular hyalopilitic andesites and pumice: a rock identical in character with those from the eastern side of the dingle. But an interesting and important feature of this tuff is, that it contains, in addition to the usual material, fragments of a devitrified rhyolite. These rhyolitic fragments mostly present a patchy appearance, such as is quite common in the rocks of Castell Cogan; while some consist solely of cryptocrystalline felspar and quartz, without any definite arrangement.

The hornblende-andesite is a pale-grey rock which weathers almost white, and is thus hard to distinguish in the hand-specimen from some of the rhyolites. It has a mean specific gravity of 2·66. Sections cut from the least-weathered portions of the flows [E 4153, 4156], which form the crags above the stream, show that the rocks are considerably decomposed. Under the microscope, they are seen to consist of phenocrysts of felspar set in a fine-grained felspathic matrix.

The phenocrysts include well-formed plagioclase-felspars, belonging to the oligoclase and oligoclase-andesine varieties, which are usually twinned according to the Carlsbad and albite-laws. In contradistinction to the augite-andesites described on p. 239, interpenetration-twins and stellate groups are uncommon.

The presence of hornblende is inferred from strongly doubly-refracting pseudomorphs, in an indeterminable micaceous mineral. These pseudomorphs (·8 mm. in length) have the external form of hornblende, and show a corrosion-border of pale-green chlorite and dusky iron-ores. The groundmass consists of a felted mass of felspar-microliths, which give almost straight extinction, and are evidently of more acid composition than the phenocrysts. The matrix is, however, considerably decomposed, and has given rise to sericitic alteration-products and secondary quartz.

The rock, as a whole, does not seem to have been vesicular; but

an indistinct flow-structure may be traced in the groundmass, especially around some of the larger phenocrysts.

(*f*) The Diabase of Tre-hyrn.

Specimens [E 4131] of this rock collected from well inside the mass, show a moderately-fresh diabase, of a dark-green colour, in which the constituent minerals are visible to the unaided eye. Under the microscope, it is seen to be coarsely ophitic, and shows large crystals of an almost colourless augite enclosing, and penetrated by, felspar-laths with low symmetrical extinction-angles. The felspars are seemingly of a composition intermediate between oligoclase and andesine, and similar to those of the first generation in the augite-andesites.

The augite is in general partly decomposed, especially along the cleavages, giving rise to chlorite, serpentinous material, and calcite, which minerals also form irregular patches in other parts of the rock. The felspars are clouded, and partly decomposed with the formation of epidote, or calcite and secondary quartz. (See Pl. XXVI, fig. 2.) Beautiful skeleton-crystals of ilmenite occur irregularly distributed through the rock, and, owing to their partial decomposition into leucoxene, they appear of a dirty-white colour when viewed by reflected light.

Other specimens [E 4129] nearer the margin of the intrusion show an almost complete absence of ophitic structure. In these the augite seems to be of two generations: the first building fairly-large idiomorphic crystals, and the second occurring as granules in the groundmass. The felspars are the same as in the other part of the rock, and are clouded by decomposition-products, while the larger crystals are considerably epidotized.

The diabase of Tre-hyrn has a distinct tendency, when traced towards its margin, to pass from the ophitic to the granular type, as is so often the case with intrusions of this character; while, in hand-specimens, the rock becomes quite fine-grained, and is then hard to distinguish from the fine-grained pyroclastic rocks belonging to the andesitic series into which it is intruded.

(*g*) The Diabase of Pentre-newydd.

This rock undoubtedly consolidated as an ophitic diabase, but now the original ferromagnesian mineral has disappeared, and its place has been taken by much calcite, dusty iron-ores, serpentine, and chlorite. The felspars appear to be oligoclase-andesine, and, so far as their decomposed state will allow us to judge, compare in composition with those in the Tre-hyrn rock.

The pseudomorphs after the ferromagnesian mineral, which consist largely of calcite, with a development of leucoxene along the traces of the cleavages, are clearly ophitic in character; but the cleavages are those of an amphibole, and not of a monoclinic

pyroxene. Therefore, we are led to infer that at some period in its history this rock was more or less completely uralitized.

In its intrusion it has included a thin lenticular mass of grits and shales; the grit consists of closely-packed subangular grains of quartz, felspar, and fine sediments, with a small quantity of interstitial chlorite and iron-ores.

2. The Rocks at Capel Bethesda.

(α) The rhyolites of Capel Bethesda are almost identical in character with those of Coomb, especially those on the eastern side of Coomb Dingle (p. 241), and have a mean specific gravity of 2·64. The spherulitic type is the more common, although the section in the road opposite the Chapel has yielded a rock poor in phenocrysts, the groundmass of which presents that patchy appearance that was noticed in some of the rocks from the Castell-Cogan area (p. 242).

The small patch of conglomerate which rests upon these rocks is largely made up of partly-rounded masses of the underlying material. Many of these pebbles were collected, and several sections cut from them. They showed, in most cases, marked spherulitic structures: the spherulites in ordinary light standing out in contrast with the groundmass, on account of their being slightly stained by oxides of iron. Under crossed nicols they present exactly similar characters to the spherulites from Coomb.

(β) The Diabase north of Pen-gelli-uchaf.—This rock is so rotten, even at its best exposure, that little can be said with regard to its original composition, except that it was at one time a diabase, and probably preserved an ophitic structure.

Now it consists entirely of almost completely-decomposed felspar-laths, together with chloritic and serpentinous minerals resulting from the decomposition of the original ferromagnesian mineral, while much calcite is developed in patches and veins. A sufficient number of felspars have portions left such as to make determination possible, and these are seen to be identical in composition with those in the diabase of Tre-hyrn.

The chlorites include the two varieties mentioned in connection with the andesites of Coomb (p. 239).

3. The Lambstone Porphyry.

The rock at Lambstone, Llangynog, is of a light greyish-blue colour, very tough, and has a specific gravity of 2·68. There is no sign of bedding, but two sets of rough joints may be noticed traversing the mass approximately at right-angles to each other.

Under the microscope, the rock is seen to be considerably decomposed, but it is still fresh enough to reveal its true character. The constituent minerals are fairly-large idiomorphic plagioclase-felspar and smaller orthoclase, with minute but well-shaped crystals of hornblende, set in a fine felsitic groundmass without any

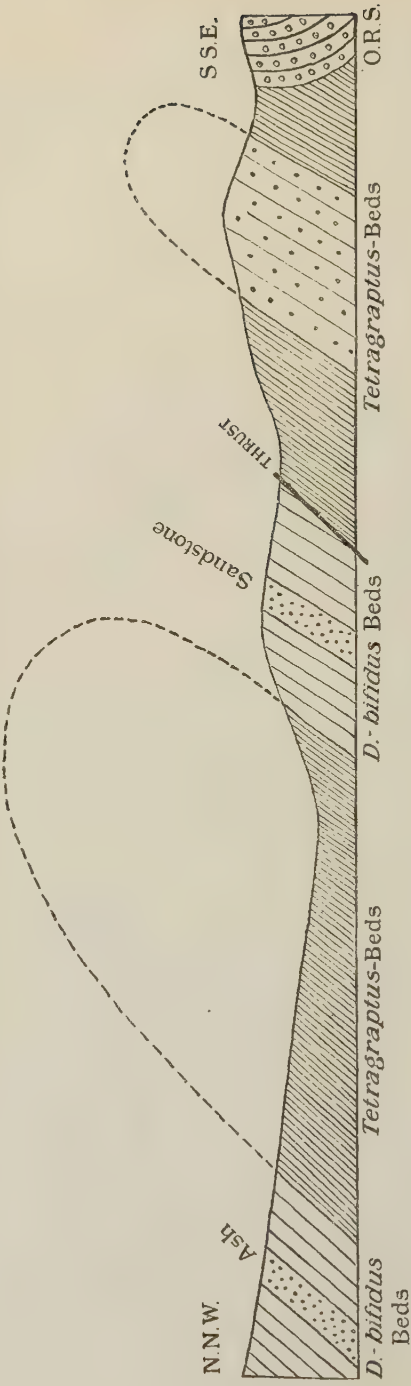


Fig. 5.—*Generalized section across the Llangynog district, from north-north-west to south-south-east.*
[Length of section = about 4 miles.]

well-defined structure. Some augite was probably also present. The felspar-phenocrysts consist of acid oligoclase, twinned according to the albite and Carlsbad laws, and giving the characteristic low maximum extinction-angles measured onto the twin lamellæ. The orthoclase is most usually untwinned. Both felspars are more or less decomposed, giving rise to secondary quartz and sericitic material.

The hornblende no longer exists as such, but is represented by pseudomorphs in pale-green chlorite with a low double-refraction. These pseudomorphs are beautifully shaped, having the angles and cleavages of the original mineral well-preserved. The cleavages are often marked by little strings of iron-ores, as also in many cases is the border of the crystal.

V. Structure, Folding, and Faulting of the District.

The structure of the district is one of great complexity, and there are many of the problems that it has presented that we do not pretend to have solved; some few salient points, however, may be regarded as certain.

The general structure of the district is

referable to two complicated anticlines ranging about east-north-east and west-south-west. Both anticlines are overfolded from the north, their southern limbs being inverted. They are separated one from the other by a thrust of steep dip, hading northwards and cutting out the intervening syncline.

These anticlines appear to owe their origin to a system of pre-Old-Red folding, but it is evident that they have been further complicated by a series of folds and faults which have affected the Old Red Sandstone.

The axis of the northern anticline[1] lies beyond the northern limit of the map (Pl. XXIII), and ranges along the low ground at Llanllwch, traversed by the Great Western Railway west of Caermarthen, the oldest beds exposed being *Tetragraptus*-shales. Its southern limb is represented by the inverted belt of *Didymograptus-bifidus* Beds ranging east and west of Cwm Crymlyn.

The axis of the southern anticline has the same general direction, and ranges through the grit-masses of Llangynog, but has suffered much fracture and displacement by later disturbances, largely determined by the differential movement between the grits and the shales. Its northern limb dips normally towards the north, but its southern limb is generally vertical or inverted.

The core of this southern anticline consists of the pebbly grits of Llangynog, which we correlate with similar grits that form the core of an anticline of like structure at Bolahaul and Cystanog, south-east of Caermarthen.

A glance at the map (Pl. XXIII) shows that most of the faults have a general west-south-westerly trend. They frequently throw off branches, which enclose lenticular strips of ground and unite again with the original line of fault. Although the faults shown are numerous, it is more than likely that others remain undetected. Whether the faults are normal faults or overthrusts is frequently unknown, but in many cases there is ground for supposing them to be thrusts.

That much of the folding and faulting was accomplished before the Lower Old Red Sandstone was deposited, is proved by the striking unconformity at the base of that formation. Thus: a mile north-east of Rhyd-lydan it rests on Tremadoc Beds; at Ffynnon-wen and Moelfre it overlies the *Tetragraptus*-shales; at Coomb and Castell Cogan it can be seen crossing the various igneous rocks of the Coomb complex, and its basement-beds are made up largely of detritus from the igneous rocks around which it wraps. South of Pentre-newydd it can be seen resting on the *Didymograptus-bifidus* shales, while a little farther to the south-west it spreads over the Bala Beds of Llandeilo-Abercowin.

Neither the fault which separates the rhyolites of Castell Cogan from the *Didymograptus-bifidus* Beds, nor that which a little farther

[1] 'Summary of Progress of the Geological Survey for 1904' Mem. Geol. Surv. 1905, p. 47.

west separates the latter from the Bala Beds (*Dicranograptus*-Shales and Bala Limestone), affects the base of the Old Red Sandstone; these faults are probably both normal faults. Other faults, however, clearly involve the Old Red Sandstone, as, for instance, those which bound the basal green beds east of Moelfre, and that which separates the same beds at Coomb from the *Tetragraptus*-Beds of Llangynog Church.

VI. Sequence and Age of the Igneous Rocks.

On the eastern side of Coomb Dingle the sequence is quite clear, and may be made out with ease. The oldest rocks exposed are those forming the southern mass of augite-andesites and their associated fragmental rocks; next in succession follows a series of perlitic and spherulitic rhyolites, of which the uppermost member is a rhyolitic fluxion-breccia of some importance. This breccia in turn was followed by another set of augite-andesites, exactly similar to those below the rhyolites.

It is a misfortune that the relations of the rocks on the two sides of Coomb Dingle are so obscure, for not only is there a discrepancy between the two sides, but the andesites on the west are themselves probably faulted off from the rhyolites of Castell Cogan. However, these andesites contain fragments of devitrified rhyolite, and it is highly probable that they were extruded later than the rhyolites.

Although there are some slight differences to be observed between the rhyolites on the east and those on the west of Coomb Dingle, we think that there is sufficient similarity in composition and mode of occurrence to warrant us in considering them as marking one geological horizon.

With the exception of the occurrence of a small thickness of hornblende-andesite (probably of extrusive origin) in the lower part of the western andesitic series, these rocks are identical in lithological characters and composition with those of the upper andesitic series on the eastern side of the dingle. As no hornblende-andesite has been met with on the eastern side, we suspect that the augite-andesite to the north of Castell Cogan may be the highest member of the series.

We therefore suggest that the sequence was, first, augite-andesites followed by rhyolites, and then another series of augite-andesites, which included a small outpouring of a hornblendic rock. The whole series was, at a later date, intruded into by diabase.

There is not much evidence to prove that the igneous rocks of Coomb and those of Capel Bethesda are on the same horizon, excepting perhaps their close proximity and the evident lithological similarity which exists between the rocks of the two areas. The rhyolites of Coomb and those of Bethesda are identical in character, and both are presumably followed by intrusions of diabase: although the latter rock in the Bethesda area is so rotten, that it has been found almost impossible to compare it with that of Tre-hyrn or Pentre-newydd.

One of the most difficult problems that confronts us is that which concerns the age of the extrusive and intrusive rocks of the district as a whole. There is, however, as we have seen, little doubt that the whole series of extrusive rocks as developed at Coomb and Bethesda may be referred to one geological horizon. The mapping of surrounding districts in South Wales has shown us that, in the Ordovician System, we might expect to meet with volcanic rocks on any of three horizons: (*a*) near the top of the zone of *Didymograptus Murchisoni*; (*b*) near the base of the zone of *D. bifidus*; or (*c*) low down in the Arenig Series; for, at all these horizons, well-developed ash-beds have been noticed.

At Llangynog the first two cases may be dismissed as impossible, for the quantity of ashy material is much greater on the north side of the main anticline, while Llangynog is on the south side, where the *Didymograptus-Murchisoni* ash is not developed, and the *D.-bifidus* ash is represented by sandstones and grits.

We are, therefore, led to the conclusion that the igneous rocks may belong to the lower part of the Arenig Group, or, failing that, to some much older group of rocks of which no sediments exist within the district.

East of Llangynog, in the neighbourhood of Caermarthen, there seems to be perfect conformity between the Tremadoc rocks with *Peltura punctata* (Crosfield & Skeat) and the Arenig Series, of which the lowest part consists largely of conglomeratic grits and sandstones. These conglomeratic grits are those which are again brought up by an anticlinal fold in the neighbourhood of Llangynog. It is improbable, although not impossible, that the Tremadoc rocks should have been overlapped, and so great an unconformity developed at the base of the Arenig Group within a few miles: which would be the case, if the igneous rocks were of pre-Arenig age. It is a significant fact that the igneous masses, on one side or the other, are always bounded by a member of the oldest Arenig sediments, and it seems that the bulk of the evidence points to the age of the extrusive rocks being that of a low horizon in the Lower Arenig Group.

With regard to the intrusive masses, it is obvious, at Coomb, that they are newer than the other igneous rocks; while at Lambstone, Bethesda, and Pentre-newydd, it may be proved that they were intruded after a certain portion of the Lower Arenig beds had been deposited.

VII. Summary.

To sum up: we find that the older sedimentary rocks of the neighbourhood of Llangynog are referable to the *Didymograptus-bifidus* Beds and *Tetragraptus*-Beds of the Arenig Series. They take the form of two main anticlines due to pre-Old Red Sandstone folding, and are unconformably overlain by Lower Old Red Sandstone. The whole sedimentary series has been subsequently affected by folding and faulting, which took much the same direction.

The igneous rocks occur in three areas, which all belong to

the same petrographical province. The order of extrusion was: (1) augite-andesites; (2) rhyolites; (3) augite-andesites, with some hornblende-andesite; and (4) intrusions of diabase and porphyry.

We adopt the view that the extrusive rocks are associated with the lower members of the *Tetragraptus*-Beds, and are consequently of Lower Arenig age; while the intrusive rocks have been injected into the extrusive rocks, and have also affected the *Tetragraptus*-Beds.

EXPLANATION OF PLATES XXIII–XXVI.

Plate XXIII.

Geological map of the igneous and associated rocks of the Llangynog district, on the scale of 3 inches to the mile.

Plate XXIV.

Fig. 1. Devitrified spherulitic rhyolite [E 4143]; crossed nicols. Some of the spherulites show a rude black cross. × 17. See p. 241.

2. Partly-devitrified perlite [E 4443]; ordinary light. × 17. See p. 242.

Plate XXV.

Fig. 1. Vesicular augitic andesite [E 4138]; ordinary light. × 17. The figure shows lath-shaped felspars, set in a groundmass that exhibits a structure approaching the variolitic. At the top of the field is a small vesicle filled with chlorite, and at the bottom a pseudomorph after augite in chlorite and secondary quartz. The chlorite shows slightly darker than the quartz. See p. 239.

2. Pilotaxitic andesite [E 4439]; ordinary light. The figure shows a mass of felspar-microliths, and a solitary felspar of an earlier generation at the top of the field. × 30. See p. 240.

Plate XXVI.

Fig. 1. Andesitic tuff [E 4163]; ordinary light. The figure shows several angular fragments of hyalopilitic andesite, with minute microliths arranged with flow-structure. At the bottom of the field is a larger fragment of andesitic pumice, the vesicles of which are filled with chlorite. The larger fragments are set in a fine groundmass of broken felspar-crystals and microliths. × 17. See p. 241.

2. Ophitic diabase [E 4131]; crossed nicols. Shows ophitic augite and partly-decomposed felspars. × 17. See p. 244.

Discussion.

The President said that he was glad to find that the Authors had obtained definite evidence of two distinct sets of movements—the one before, the other after, the deposition of the Old Red Sandstone. He himself, when working with the late Mr. Thomas Roberts in the Haverfordwest district, had been unable to obtain evidence bearing on this question, owing to the profound faulting which had there occurred.

Prof. Groom said that geologists would heartily welcome another incursion into the obscure geology of the Welsh borderland. Knowing the ground himself, he was convinced of the accuracy

FIG. 1.

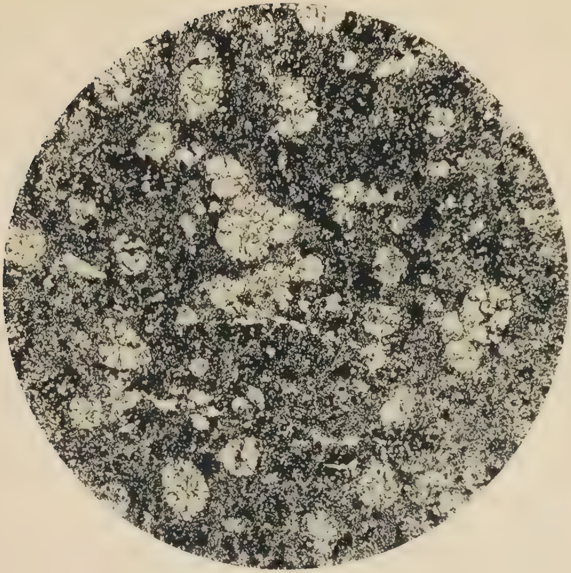
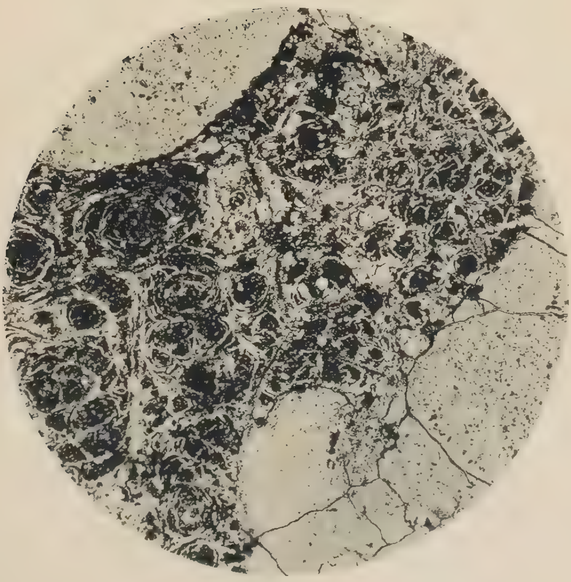


FIG. 2.



IGNEOUS ROCKS FROM LLANGYNOG.

T. C. Hall, Microphoto. *Bemrose, Collo.*

FIG. 1.

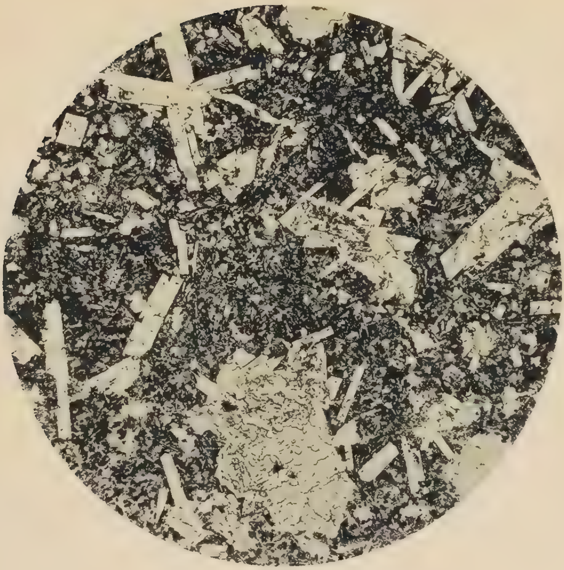
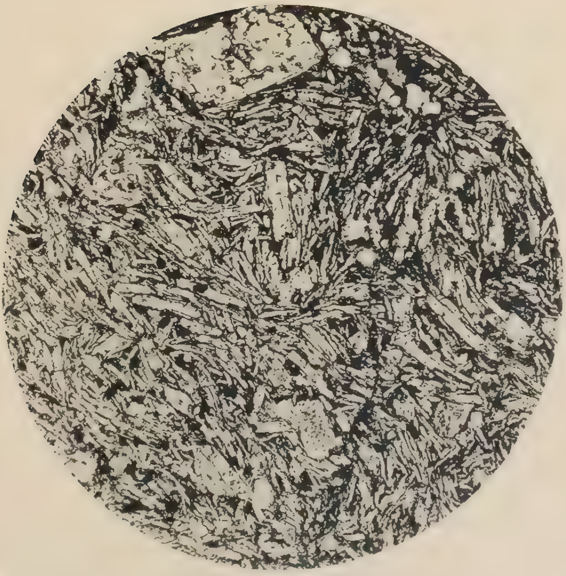


FIG. 2.



IGNEOUS ROCKS FROM LLANGYNOG.

T. C. Hall, Microphoto. *Bemrose, Collo.*

FIG. 1.

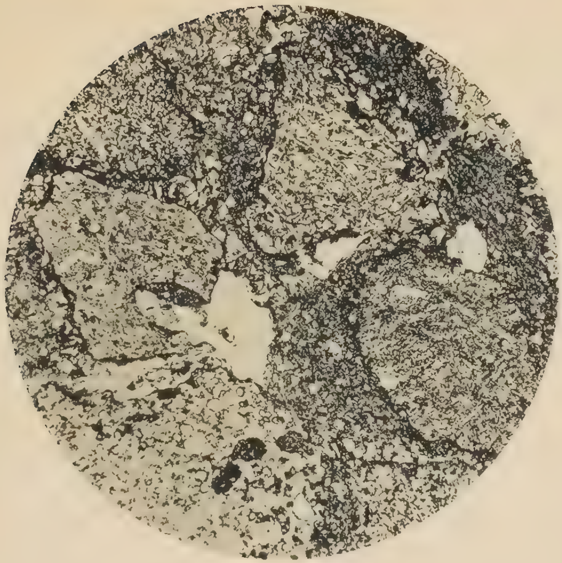


FIG 2.

IGNEOUS ROCKS FROM LLANGYNOG.

T. C. Hall, Photomicro. *Bemrose, Collo.*

of the Authors' work. In regard, however, to the sandstone with a conglomeratic base unconformably overlying the Ordovician Series, described by the Authors as Old Red Sandstone, he was impressed, when he visited the district, with the idea that it was possibly of Downtonian age. The speaker described a set of beds much resembling Old Red Sandstone, but enclosing marine Downtonian fossils, from the neighbourhood of Llangadock. Remembering that these beds thinned out, changed colour, and became less fossiliferous as they were traced towards the area dealt with by the Authors, it seemed quite possible that the grey sandstones which they described might represent Downtonian deposits that had overlapped the underlying Silurian, and he would like to ask whether the Authors could give satisfactory proof that this was not the case.

Mr. J. V. Elsden said that he had taken particular interest in the igneous rocks described by the Authors, who had suggested a possible resemblance between the Lambstone porphyry and the lime-bostonites and oligoclase-porphyrites occurring farther north, in Pembrokeshire. So far as he could judge, the Lambstone-rock differed chiefly in having a less felspathic groundmass; but only a chemical analysis could determine the question satisfactorily. The alternations of andesites and rhyolites, mentioned in the paper, were especially interesting, and suggested the possibility of the Lambstone intrusion representing part of a later dyke-phase of the same volcanic sequence. A similar explanation was also possible in Pembrokeshire, where the speaker had shown reasons for assigning the lime-bostonites to an earlier period than the diabase-intrusions. The absence of rhombic pyroxenes from the Llangynog diabases was significant, in view of their great abundance in the St. David's-Head district.

Mr. W. G. Fearnsides congratulated the Authors upon their additions to our knowledge of the Ordovician rocks of South Wales. He enquired whether the igneous series described would fall within the zones of *Didymograptus extensus* and *D. hirundo*, remarking that in Southern Merionethshire Ramsay had observed very similar rocks within what would now appear to be the limits of these zones. He was glad to hear of one more district wherein later igneous intrusions are practically confined to the immediate neighbourhood of the rigid masses of the earlier volcanic outpourings.

Mr. Cantrill pointed out that the mapping of the Llangynog and adjacent districts clearly establishes the fact that there have been at least two periods of movement along the same general east-north-east and west-south-west lines. That the first antedates the Lower Old Red Sandstone is proved by the manner in which that formation crosses the outcrops of various members of the Cambrian and Ordovician systems and of the igneous rocks of Coomb. A subsequent movement is equally clearly later than the Old Red Sandstone, for that formation is not only much folded, but is faulted deeply between some of the Ordovician subdivisions.

That the green beds at the base of the Old Red Sandstone cannot be assigned to the Downtonian seems clear from the existence of

the great break at their base, and from the fact that they consist of marls, sandstones, and cornstones, indistinguishable except in colour from the lower part of the Old Red Sandstone; moreover, they pass by alternation upwards into the ordinary red marls. Finally, they are unfossiliferous, and, until they yield a Silurian fauna, they can be regarded only as the basement-beds of the Old Red Sandstone.

In reply to Mr. Fearnsides, he considered that the *Tetragraptus*-Beds should be taken to include the zones of *Didymograptus hirundo* and *D. extensus*; but in the Llangynog district the lower beds cease to yield graptolites, and therefore may belong to the *D.-extensus* Zone or to a lower horizon of the Arenig.

Mr. THOMAS, after thanking the President and Fellows for their kind reception of the paper, said that he was in perfect agreement with the remarks made by Mr. Cantrill. In reply to Mr. Elsden, he said that it was quite possible that the two types of intrusive rocks (diabase and porphyry) might be the dyke-equivalents of the andesite and the rhyolite respectively; with regard to the occurrence of rhombic pyroxenes in the diabases or andesites, careful search had failed to reveal any pseudomorphs after these minerals.

12. *The* Buttermere *and* Ennerdale Granophyre.

By Robert Heron Rastall, M.A., F.G.S., Fellow of Christ's College, Cambridge. (Read January 24th, 1906.)

[Plates XXVII & XXVIII—Microscope-Sections.]

Contents.

I. Introduction.

In the western part of the English Lake-District there occurs a large development of igneous rocks, which are conveniently described, collectively, as the Buttermere and Ennerdale Granophyre. This group extends for nearly 10 miles from north to south, and for nearly 5 miles from east to west. In this large area are to be found several different rock-types, which present many features of interest; and, at the suggestion of Dr. J. E. Marr, F.R.S., I have undertaken the investigation of the phenomena shown in this district.

The first and only detailed description of this rock-mass was given by Clifton Ward [1] nearly 30 years ago; and the subject has apparently never been touched as a whole by modern methods, although Mr. Alfred Harker [2] has published a short description of some specimens from the Wastwater district.

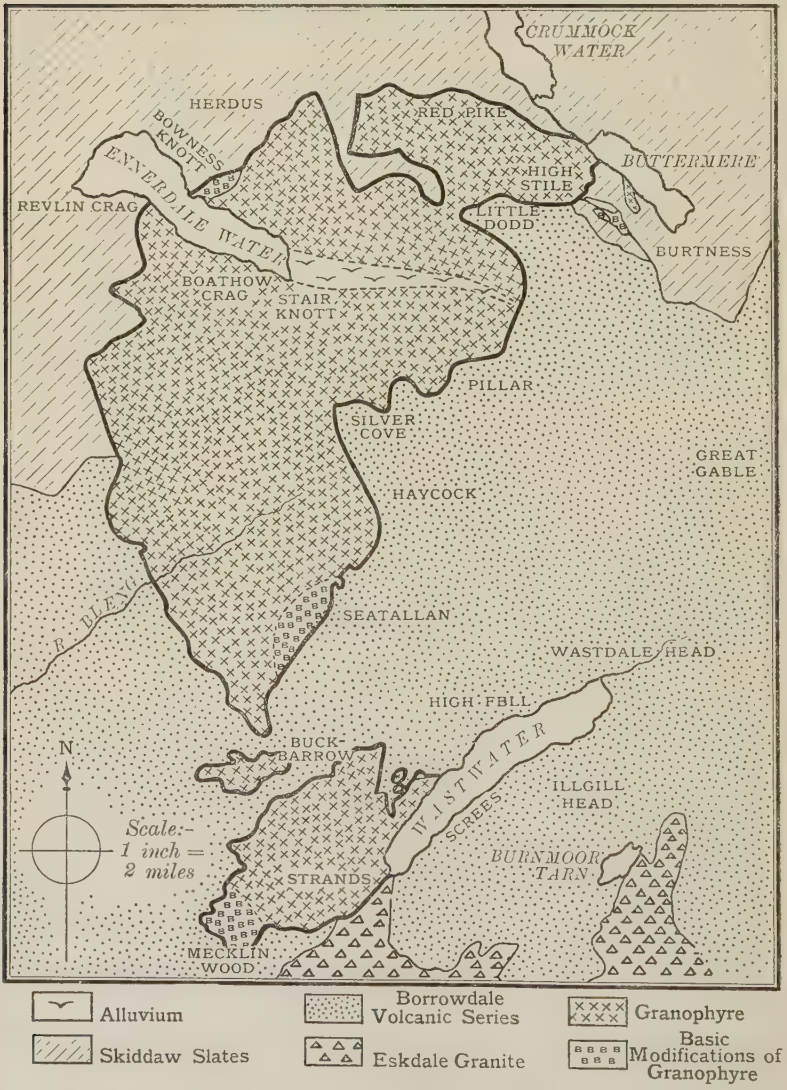
II. Field-Relations.

The map (fig. 1, p. 254) shows that the exposure of this group of rocks is very irregular in form: to the west of Buttermere is a somewhat lenticular mass about $2\frac{1}{2}$ miles long by nearly a mile wide, forming the lower part of High Stile, and the main mass of Red Pike and Gale Fell. The southern boundary of this intrusion cuts across the summit of Red Pike; and there is a strong contrast between the rugged crags of High Stile, formed of volcanic rocks of the Borrowdale Series, and the smooth outlines given by the intrusive rocks of Red Pike. This intrusion is connected with a much larger mass to the south by a narrow neck on Little Dodd; and this neck is very conspicuous even from a distance, by reason of the weathering-out of blocks of granophyre, contrasted with the peat-covered Skiddaw Slates and Borrowdale volcanic rocks on the west and east respectively.

[1] Quart. Journ. Geol. Soc. vol. xxxii (1876) p. 14; also 'Geology of the Northern Part of the English Lake-District' Mem. Geol. Surv. 1876, p. 31.

[2] 'Notes on North of England Rocks' in 'The Naturalist' 1889, p. 209.

Fig. 1.—*Geological map of the district around Ennerdale Water, Buttermere, and Wastwater, on the scale of 2 miles to the inch.*



The larger mass on the south is almost cut in two by the alluvium of the Ennerdale Valley; and it might be supposed that this valley was determined by a strip of softer rock between two intrusions: but I have examined all the lowest accessible points in the floor of the valley, and everywhere found granophyre *in situ*. I have no doubt, therefore, that the intrusion is perfectly continuous; and the detailed mapping at the western extremity certainly suggests that the true form of the intrusion is shown by simply joining up the boundary-lines on each side of the lake. It is probable that Ennerdale is a line of weakness on a large scale, which is due to subsequent earth-movement. There is a great fault running in a north-north-westerly direction, from the head of Smithy Beck towards Floutern Tarn, which shifts the outcrop more than a mile to the north-west, and this helps to make the outline appear more complicated.

The western boundary is fairly simple to the south of Ennerdale Water. It runs in a sinuous manner, with a general southerly direction, for some distance south of the Bleng Valley, and then it suddenly turns to the north-east. Throughout this whole distance of some 6 miles the line is very difficult to follow accurately, although easy enough to map approximately. The outcrop is occasionally shifted for a short distance by small faults, but no important dislocations seem to occur.

Returning again to Ennerdale, a very fine junction-section can be seen in the bed of the River Liza, close to the new bridge below the Pillar mountain. Here the volcanic rocks have been much hardened and injected by veins of granophyre, and this hard band has given rise to a small gorge, which affords a fine exposure. The junction here appears to be very irregular.

From High Beck westwards, the line of junction with the Borrowdale Series presents some interesting features. The faults indicated on the 1-inch map seem to be non-existent; but, from a consideration of the outcrop of the line of junction in relation to the contour-lines, it is evident that the plane of separation between the Volcanic Series and the granophyre is here dipping north-westward, instead of south-eastward as usual. This dip is at a gentle angle, perhaps 5°; and the upper surface of the granophyre is nearly always brecciated along the plane of junction. Hence, it seems probable that there has been a certain amount of movement along this plane.

On the hillside west of Buckbarrow appears a small lenticular patch of similar rock, and south of this again comes a larger mass, occupying most of the low ground to the west of the foot of Wastwater. This mass is very badly exposed, especially round its margin, and was only mapped with great difficulty.

As will appear from the petrographical descriptions which follow, this great series of intrusions is far from uniform. The great bulk of the rock is highly acid; but in many parts there are more basic modifications, which require separate description. These basic modi-

fications are always marginal, and numerous traverses have failed to disclose any such in the inner parts of the large masses.

On the whole, dykes are scarce. There are a few interesting examples in Burtness Combe, Buttermere, and a very complex system of dykes on Yewbarrow; but as the latter may, and probably do, belong to the Eskdale Granite, I have not attempted to describe them.

The generalized strike of the Lower Palæozoic rocks of this part of the Lake District is nearly due north-east and south-west, with a south-easterly dip; on the western side the strike swings round more towards north and south, and the outcrop of the granophyre-mass closely follows this somewhat curved line. On the whole, the intrusion seems to be intimately connected with the plane of junction between the Skiddaw Slates and the succeeding Volcanic Series. It may be regarded as consisting of a series of laccolites, which are possibly, in part, of the 'cedar-tree' type. This applies especially to the southern part of the area, where it appears that the intrusion has penetrated into the Volcanic Series. The top of Illgill Head, east of Wastwater, consists of the base of the Scawfell Ashes; hence, the slope covered by the Wastwater Screes must be occupied by the 'streaky'[1] series: therefore, unless there is an enormous fault down Wastwater, the top of the southern granophyre must be well up in the Volcanic Series. The base of the granophyre, near the head of Crummock Water, obviously rests upon the Skiddaw Slates: hence, it appears that the granophyre not only arches up the Volcanic Series, but penetrates into it as well.

The peculiar form of the northern part of the exposure seems most easily explicable on the supposition of two laccolites: a small one on the north, connected with a very large one on the south of it by a narrow neck, which is exposed on Little Dodd. These two laccolites appear to be, on the whole, at the same horizon, namely, the plane of junction of the Skiddaw Slates and the Volcanic Series: this plane seems to have undergone a certain amount of warping, as the result of subsequent movements.

The northern or Buttermere laccolite is of a somewhat lenticular shape: it is certainly truncated at its western end, but it appears to be bounded on this side by a line of disturbance, and it is possibly faulted. Near this north-western corner are a few lenticular patches of Skiddaw Slate resting upon the granophyre, and these suggest that the original outline of this mass was irregular, somewhat of the 'cedar-tree' type. The eastern end of the laccolite is undoubtedly connected with the small igneous complex of Burtness Combe; and there is an isolated mass of granophyre in Burtness Wood, which probably forms an easterly continuation of the same mass.

A series of specimens taken from this laccolite show interesting variations. Those from near the margin [4748–50, 4752][2] are

[1] E. E. Walker, Quart. Journ. Geol. Soc. vol. lx (1904) p. 89.

[2] Numbers in square brackets, throughout this paper, refer to slides in the collection of the Sedgwick Museum, Cambridge.

granitic in the usual sense (Pl. XXVII, figs. 1 & 2). A short distance from the margin [4751] granophyric structure begins to appear; specimens taken from the middle of the laccolite, as for example at the head of Near Ruddy Beck, are poorly-developed granophyres [4753].

On the hillside a few hundred yards west of Scale Force, the junction with the Skiddaw Slates is very well seen, and the metamorphism can be well studied here. Close to the intrusion the slate is altered to a very compact greenish hornstone, and the junction is absolutely sharp. The original bedding of the slate is well seen on weathered surfaces, but there is no trace of cleavage; and it is quite clear that the intrusion of the igneous rock was anterior to the movements which produced the cleavage of the Skiddaw rocks.

Along the northern side of this laccolite are a number of lines of disturbance, which have produced small tear-faults crossing the junction at right angles; these are made conspicuous by a great development of hæmatite. The fine waterfall of Scale Force, 156 feet high, is determined by one of these; and the stream has here cut a very deep gorge along the line of weakness.

The second mass is much larger, and the laccolitic form is not here so obvious; it is probably concealed, to a certain extent, by incomplete denudation and faulting. In this case granophyric structure is carried to a very high degree of perfection. The margin of this intrusion is variable in character, sometimes granitic, more often coarsely graphic; and in some localities felsitic, as, for example, in Revlin Crag, on the south side of Ennerdale Water, and at Silver Cove [4754], farther east. The farther we proceed from the margin the finer in texture and more complex is this micrographic or granophyric structure seen to become [4755]; see Pl. XXVIII, fig. 1. The best examples come from near the middle of the exposure, at Mart Knott, Stair Knott, and Sail Hills, south of the head of Ennerdale Water, and in the bed of Woundell Beck, close to its junction with the River Liza [4756–59]; see Pl. XXVIII, fig. 2. Here also the normal rock is traversed by fine-textured veins of an aplitic nature, which show no micrographic intergrowth at all, and are singularly poor in ferromagnesian minerals [4760-61]. They are presumably of later date than the rest.

On the south-east side of this mass, on the flanks of Seatallan, is seen a considerable development of a rather more basic variety, characterized by the occurrence of needle-shaped crystals of ferromagnesian mineral, often an inch long.

In the smaller laccolites, in the Wastwater district, some interesting variations occur; and especially in the neighbourhood of Mecklin Wood, about a mile north-east of Santon Bridge, the whole intrusion becomes very complex, and some peculiar rock-types are found. These are the freshest rocks in the district, and their study has thrown much light on the more weathered examples from the northern part of the area.

III. Petrographical Descriptions.

(a) The Normal Rock.

The macroscopic appearance of an average specimen is that of a rather fine-textured granite, usually of a bright pink colour, but sometimes grey with only a slight tinge of red. Near the margin it is often grey or even greenish, owing to the higher proportion of coloured minerals; and in certain localities there are also varieties which are quite dark-grey or blue, but these demand separate description. The rock is very rarely porphyritic to the unaided eye, and dark-coloured 'basic patches' are also scarce. In places the rock is somewhat drusy, and in the neighbourhood of planes of disturbance it is often much stained by hæmatite.

I have examined a large number of slices, which have been selected, as far as possible, so as to illustrate the different types, and the variations that occur in different parts of the mass.

The rock consists essentially of quartz, various felspars, chlorite representing ferromagnesian minerals, and accessories. The coloured minerals generally occur in small proportion only; and, on the whole, the rocks are distinctly leucocratic in character.

Quartz is generally very abundant. It contains the usual fluid-inclusions, which are nearly always very conspicuously arranged in lines; and these lines are often appreciably parallel throughout the slice, as if their position was determined by strains set up during cooling or subsequently. The relations between the quartz and the felspar, with regard to age, are very variable; in the granitic types [4748–50, 4752] the quartz appears to have crystallized partly before the felspar, as in the Shap Granite and parts of the Eskdale Granite. In this case, the quartz occurs in small crystals which sometimes show fairly-good hexagonal outlines, but more often they are more or less rounded in form. In the great mass of the rock, however, the quartz and the felspar have crystallized simultaneously, giving rise to more or less perfect granophyric structure [4755–56, 4758–59].

The felspars are very variable, and include orthoclase, perthite, and plagioclase; in a few specimens a very little microcline appears to be present. The relative proportions of orthoclase and plagioclase vary greatly, but the latter is generally the more abundant; in some slices it appears to be almost the only felspar present. Both kinds of felspar are generally somewhat decomposed, being partly converted into aggregates of small flakes of white mica, and these flakes generally lie parallel to the cleavages of the felspar: wherefore, in most sections, they appear to be arranged in two sets at right-angles. However, the decomposition has rarely gone far enough to mask the twinning, which is generally conspicuous.

In spite of decomposition, it is often obvious that much of the unstriated felspar possesses poorly-developed perthite-structure, and the so-called 'orthoclase' must contain a good deal of the albite-molecule.

In the granitic forms, orthoclase, perthite, and plagioclase all occur as large idiomorphic or hypidiomorphic crystals. The orthoclase and perthite are twinned on the Carlsbad law, and are of quite normal character. In the granophyric forms also, orthoclase occurs in graphic intergrowth with the quartz.

In most examples the dominant felspar is a rather turbid plagioclase, which occurs in fairly well-formed crystals in nearly all varieties. It is commonly twinned on the Carlsbad and albite-laws; the twin-lamellæ are often rather indistinct, owing to decomposition. Occasionally other twins appear, such as the pericline and Baveno varieties. The plagioclase-crystals are sometimes slightly zoned, but the range of composition between the inner and outer zones is not wide. Examination of a very large number of symmetrical sections shows that, in the majority, the extinction is nearly straight. Some examples show extinction-angles up to about 20°; and in these cases a comparison of the index of refraction with that of quartz proves that andesine and albite are both present.

The analysis tabulated by Clifton Ward[1] is probably not very trustworthy; but, if we assume it to be moderately correct, the percentages of soda and lime which are there stated, supposing all to be combined as felspar, would give an approximate ratio of Ab : An = 6 : 1. But some of the soda exists as perthite, and the true ratio must be somewhat lower than this.

The determination of the original character of the ferro-magnesian mineral of this rock presents a certain amount of difficulty. Clifton Ward regarded it as hornblende, while Dr. Teall, in his 'British Petrography,' merely refers to it as 'green chloritic aggregates.'

In most specimens the coloured mineral is some variety of chlorite, but in a few especially-fresh examples from well-glaciated localities I have found almost unaltered biotite of a yellowish-brown colour, and in the normal rock the chlorite undoubtedly represents this mineral; while, in the more basic modifications from Bowness Knott, Seatallan, and elsewhere, it is equally clear that much of the chlorite is derived from augite.

The chlorite of the normal rock occurs in ragged flakes having the form of biotite; it is of a rather deep-green colour, and strongly pleochroic ($\mathfrak{a}$ deep green, $\mathfrak{c}$ pale yellowish-brown). The extinction is straight, parallel to the cleavage of the original biotite. This mineral is only distinguished from green biotite by its extremely-weak double refraction; sections of the ordinary thickness generally give a steel-grey of the first order, while many are completely isotropic. The flakes of chlorite very often enclose rather large crystals of a mineral with high refractive index and strong double refraction: this appears to be epidote. These inclusions are surrounded by a well-marked dark 'pleochroic halo' [4763].

The characters of the green mineral seem to agree best with the variety of chlorite known as pennine, while a few sections

[1] Quart. Journ. Geol. Soc. vol. xxxii (1876) p. 22.

showing rather stronger double refraction may be referred to clinochlore. However, for all practical purposes it is sufficient to regard it as chlorite derived from original biotite. Description of the chlorite derived from augite may be deferred, until the local modifications in which it occurs are dealt with in detail.

Some common accessories are magnetite, apatite, sphene, zircon, epidote, and calcite: they do not call for any special remark. The calcite is always secondary, and so is probably some of the epidote: however, the inclusions of epidote in the chlorite may be original.

A slice [4762], taken from near the margin of the small mass which lies on the hillside west of Buckbarrow, shows a remarkable facies. Instead of being, as we might expect, of very fine texture, it is the coarsest and most granitic type yet obtained. The rock is almost free from coloured minerals, only a very little of the ordinary chlorite being present. It consists of a coarse-grained aggregate of various felspars and quartz, with typical hypidiomorphic granular structure; in places only is there a very slight tendency to graphic intergrowth of the quartz and felspar. There is a large amount of felspar showing albite-twinning, and belonging to oligoclase-albite and albite. The remainder is perthite, in less perfectly-formed crystals, which very frequently have a cross-hatched character, resembling that of microcline in certain sections.

Specimens taken from the southernmost or highest laccolite show the same type of structure as that which is seen in the marginal parts of the larger masses on the north; and they may be described briefly as belonging to the granitic type, with only very slight indications of micrographic intergrowth. Their texture is not conspicuously finer, and felsitic modifications are not found to any extent. The small hill known as Berry How, about half a mile north of Strands, consists of a reddish rock, which in the field appears to resemble strongly the felsitic rock of Revlin Crag and Silver Cove; but, under the microscope, it is seen to be identical with the metamorphosed Borrowdale volcanic rocks of other parts the district.

(*b*) Felsitic Modifications.

In some localities, as at the head of Silver Cove [4754] and on Revlin Crag, the rock becomes very fine in texture, and in hand-specimens presents a felsitic appearance. In slices it sometimes shows a slight tendency to porphyritic structure. These fine-grained varieties vary considerably in composition. In the specimen from Revlin Crag quartz is practically absent; whereas at Silver Cove it is abundant. The felspar is generally much decomposed, and coloured minerals are practically absent. These felsitic modifications are all marginal, and may be regarded as chilled edges.

(*c*) The Greisen.

On the margin of the northern laccolite, a mile west of Scale Force, a curious modification of the granitic rock is to be found [4764–65]. The rock here is of the coarse-textured, non-granophyric type. It consists of quartz and muscovite, without felspar, but with the usual chlorite in small quantity—part of the quartz is of the normal type, and full of the habitual liquid inclusions; the rest of the rock consists of an aggregate of small flakes of muscovite, embedded in clear quartz. In parts there is a good deal of calcite. This may be described as a greisen.

The structure is here similar to that found elsewhere at the margin, and the ferromagnesian minerals and accessories are quite normal. There can be no doubt that the rock originally contained the usual felspar, which has decomposed, presumably under the influence of some pneumatolytic agent. The alkali-felspar molecule has formed quartz and mica, as in the case of the Cornish greisens, while the lime-felspar molecule has given rise to calcite. In some places the original felspar is not quite obliterated, and still shows traces of albite-twinning.

(*d*) Aplitic Veins.

At Stair Knott, on the south side of Ennerdale, the granophyre is traversed by some fine-textured dykes, or veins, of rather peculiar character. The macroscopic appearance of the rock is felsitic, and in slices the structure is seen to be very different from that of the normal granophyre.

The rock [4760–61] consists of quartz, felspars, chlorite, and various accessories. A few fairly-large porphyritic felspars are present; they all show albite-twinning and generally pericline-twinning also; the angle of extinction on the albite twin-lamellæ varies from 0° to 20°, and the refractive indices show that the composition ranges from oligoclase to albite.

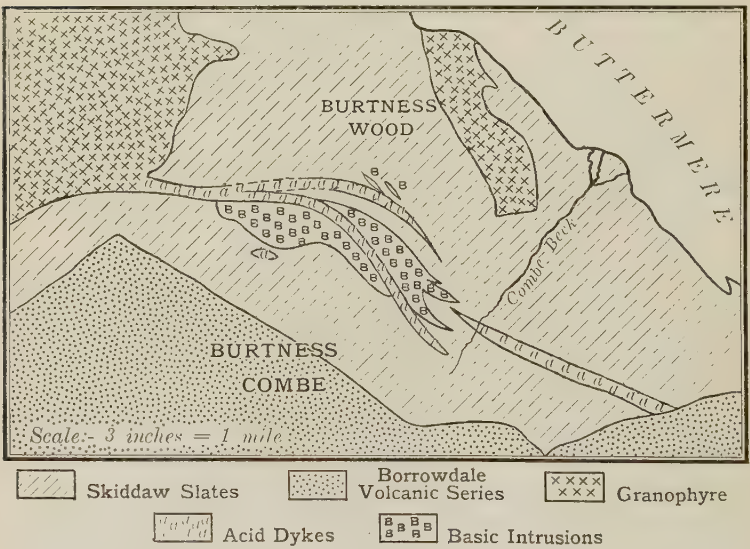
The groundmass consists of a fine-textured aggregate of small grains of quartz, and rather ragged prisms of the same felspar as in the phenocrysts. The chlorite also is markedly acicular, and consequently the general appearance is somewhat trachytic. Common accessories are small crystals of magnetite and hæmatite, prisms of apatite, and small grains of epidote of various colours, generally green or yellow, but sometimes colourless; this appears to be an original constituent. The amount of coloured mineral is very small, and the bulk of the rock consists of quartz and felspar in approximately-equal proportions. Hence, it must be of acid composition, and it is most conveniently referred to the aplite-group.

(*e*) The Igneous Complex of Burtness Combe, Buttermere.

On the flanks of High Stile, on the west side of Burtness Combe, occurs an interesting igneous complex on a small scale, which has

been briefly described by the late E. E. Walker.[1] This consists of a somewhat lenticular mass of basic rock, about a quarter of a mile long, which at its eastern extremity runs out in a beautiful fringe of dyke-like prolongations, intruded along the bedding-planes of the Skiddaw Slates. Associated with this are some good examples of acid dykes, which are evidently of later age, and show some striking variations. (See sketch-map, fig. 2, below.)

Fig. 2.—*Sketch-map of the igneous complex of Burtness Combe, Buttermere.*



The basic rock may be regarded as a small laccolite, which, owing to the present high south-easterly dip of this part of the district, is exhibited practically in cross-section. The basic intrusion is by no means uniform throughout, but shows some interesting variations. At the margin it is a fine-grained dark-green rock, and the same type is also found in the fringes at the eastern end. Passing towards the centre of the main mass, the rock is seen to become gradually coarser in texture and lighter in colour, until at the centre it is a moderately-coarse rock of doleritic character, with a distinctly pink colour in irregular patches. According to Walker[2] the silica-percentage of the basic margin is (from two analyses) 50·12 and 49·52. In a specimen of the coarse pink-spotted rock from the centre, I found 56·03, 56·10, and 56·16 per cent. of silica; there is, then, evidently a considerably higher silica-percentage in the middle.

[1] Quart. Journ. Geol. Soc. vol. lx (1904) p. 83. [2] *Ibid.* p. 84.

An examination of a series of slices shows that the rock is very far from fresh; but it was, near the margin [4766], an ophitic augite-dolerite of typical structure. The only ferromagnesian mineral present appears to have been augite, which is now represented by actinolitic hornblende; epidote, zoisite, calcite, chlorite, etc., are also abundant, derived from 'saussuritized' felspar.

Towards the middle of the intrusion [4767] the rock is much fresher, and more acid in character. It contains large idiomorphic crystals of plagioclase, which show extinction-angles corresponding with andesine and oligoclase; there are also some crystals showing twinning on the Carlsbad law only, which must be identified as orthoclase. The chief coloured mineral is ophitic augite, sometimes replaced by actinolitic hornblende and the usual type of chlorite. A fair proportion of quartz is also present; and there is a certain amount of groundmass consisting of a beautiful micropegmatite of quartz and felspar. All slices of this rock show apatite and ilmenite as abundant accessories; the latter is often converted into leucoxene. Epidote, zoisite, chlorite, and calcite are abundant as decomposition-products.

The outer margin of this rock contains a very high proportion of coloured minerals: in fact, in one slice I estimated them to amount to 75 per cent. of the whole, while at the centre they are much less abundant.

The facts just stated suggest that the magma has undergone a certain amount of differentiation after intrusion, leading to a concentration of basic minerals at the margin; but this explanation seems insufficient to account for all the phenomena, especially the occurrence of orthoclase and quartz in the pink-spotted middle part. This type shows very strong affinities to the neighbouring granophyre, and it seems probable that its peculiar character can best be explained on the supposition that it is a mixture-rock. According to this view, the basic dolerite was first intruded, and while it was still hot and partly liquid in the middle another injection of more acid character took place from the same source, and penetrated into the still unconsolidated centre of the earlier intrusion, producing a hybrid rock, intermediate in character between granophyre and dolerite. Exposures in the field support this view, and it is in accordance with observations made on the Bowness-Knott mass (p. 265).

Associated with this basic intrusion are some beautiful examples of acid dykes. One of these runs parallel to the lower margin of the dolerite for the greater part of the length of the exposure, and some distance below it; perhaps 40 or 50 feet. The other dyke first appears some distance to the east of the eastern extremity of the dolerite, and cuts obliquely across it; on reaching the lower margin of the dolerite it turns parallel to it, and forms the base of the intrusion, until the latter disappears. The acid dyke, however, is continued westward across the flanks of High Stile, and can be traced into the main outcrop of granophyre on the east side of Bleaberry Combe.

This upper dyke is very variable in character. In parts it is a dark greenish-grey, fine-grained rock of somewhat porcelain-like appearance, translucent on thin edges, and with a very splintery fracture. This facies strongly recalls the eurite of Cader Idris, described by Prof. G. A. J. Cole & the late Mr. A. V. Jennings.[1] It passes gradually into a slightly-coarser type, in which banding becomes very conspicuous, in alternate streaks of reddish and blue-grey colours. The darker minerals show a strong tendency to aggregation into rounded patches, and this often passes into very well-marked spherulitic structures. This banding is obviously a flow-structure, and both it and the spherulites are very well brought out by differential weathering. These flow-bands are often very highly contorted, as if the magma had been very viscous during intrusion. This dyke shows a striking resemblance to the rhyolite-dykes of Druim-an-Eidhne in Skye, described and figured by Mr. Harker.[2] Here also the rhyolitic affinities are very marked, though the dyke is visibly an apophysis of the granophyre. Near the eastern end of the dolerite-mass this dyke is nearly 20 feet thick, and its structure is strikingly columnar; the upper and lower layers are highly contorted, while the middle part is comparatively free from banding: where the dyke is thinner, practically the whole of it shows complex flow-banding.

The microscopic structure of this rock was described by the late E. E. Walker,[3] and its silica-percentage was found to be about 72, so that it is a distinctly-acid rock [4768].

I cannot agree with Walker's conclusion that 'the felsite was probably first intruded, and the diabase came up later' (*loc. cit.*). The dolerite-intrusion is most clearly cut by the acid dyke, which must be the later of the two. (See sketch-map, fig. 2, p. 262.)

The lower dyke is very similar in character, but less variable; it is a fine-grained rock of 'felsitic' type, showing no very definite characters except slight banding. It runs parallel to the lower margin of the dolerite, but thins out before reaching the wall on the west of Combe Beck. It can be traced for a long distance westwards across the steep slopes of High Stile, and approaches very near to the upper dyke. Unfortunately the ground is obscured by screes, and very inaccessible, so that its western prolongation is hidden; but I believe that it joins the upper dyke before the latter merges into the granophyre.

The published 6-inch Geological Survey-map shows a long felsite-dyke, running from the south-eastern extremity of the dolerite for a mile or so in a south-easterly direction past Low Wax Knott, with an interruption where it passes beneath the lag-plane. The western end of this is presumably the remarkable mass of spherulitic or

[1] Quart. Journ. Geol. Soc. vol. xlv (1889) p. 433.

[2] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 283 & pls. xi–xii.

[3] Quart. Journ. Geol. Soc. vol. lx (1904) p. 84.

orbicular rock described by Walker.[1] However, it is not clear what is the relation of this dyke to those previously described, since there is a great accumulation of fallen blocks at the critical point. They are certainly not directly continuous, but probably they are closely connected.

I have very grave doubts whether the dyke shown in the published map at Wax Knott is really a continuation of the acid dyke of Burtness Combe; my specimen, taken just below the Scarth-Gap path, is a dark-grey rock of basic appearance, and distinctly porphyritic.

(*f*) Bowness Knott and Herdus.

At Bowness Knott, on the north side of Ennerdale Water, occurs another comparatively-large area of basic rock. This is a mass, roughly oval in shape, and about a quarter of a mile in its longest diameter. On the south-east side, however, it passes into the granophyre in so irregular a manner that its boundary cannot be exactly laid down on the 6-inch map. The basic rock is penetrated by numerous veins of granophyre, which gradually become increasingly abundant, until it shades off insensibly into the main mass.

The greater part of the basic rock [4769–70] is very similar to that of Burtness Combe. It is essentially of doleritic character, but has a few special peculiarities. The felspars are usually idiomorphic, and seem to have a wide range in composition. Zonary banding is common, and the composition ranges from a rather basic labradorite to oligoclase, while a considerable amount of orthoclase appears to be present. Quartz is rare, and there is no sign of micropegmatite. The only ferromagnesian mineral is actinolitic hornblende, representing original augite, and in a few crystals relics of almost unaltered augite can be seen. In places there is a slight tendency to ophitic structure. Ilmenite is abundant, and occurs in rather large crystals.

Near the junction with the granophyre is a basic rock of peculiar character, in which the ferromagnesian mineral shows a very well-marked needle-like habit. It consists of large felspar-crystals, of columnar habit, ranging from labradorite to oligoclase, together with a good deal of orthoclase, long needles of partly-uralitized twinned augite, chlorite, epidote, ilmenite, and apatite. The rock is much weathered, but it is easy to see that the structure is not uniform throughout; in some parts of the slice there is the usual association of chlorite and epidote representing biotite, whereas in other parts the chief coloured mineral is uralitized augite. In places there is a good deal of a microcrystalline groundmass, which appears to contain quartz; but it is not micrographic. Another slice of a similar rock is coarser in texture, and does not show the fine groundmass; apparently quartz is absent from this type.

It is evident that this rock is very variable in character in different

[1] Quart. Journ. Geol. Soc. vol. lx (1904) p. 84.

parts, and the specimen containing a fine-textured groundmass might be described as an augite-porphyrite. But the evidence shows that these peculiar types are hybrid or mixture-rocks; and in this case the mixture seems to have been very imperfect, thus accounting for the patchy structure. The needle-rock occurs near the very irregular boundary between the basic and acid rocks, and is probably due to the action of a second intrusion of more acid character (namely, the granophyre of the largest laccolite), while the earlier basic intrusion was still hot. It is, therefore, probably due to the remixing of two partial magmas previously separated by deep-magmatic differentiation.

A similar type of 'needle-rock' also covers a large area on the south-eastern margin of the largest laccolite, on the southern flank of Seatallan. In petrographical character it is very similar to the rock described above, and does not require separate treatment.

A similar acicular habit of the augite has been noticed by Mr. Alfred Harker [1] in marginal modifications of the Carrock-Fell Granophyre; and he compares it with the blade-like habit of the biotite on the margins of the Shap Granite and several intrusions of granite-porphyry in other parts of the Lake District.

(*g*) The Wastwater District.

About three-quarters of a mile north-east of Santon Bridge, on the north side of the road to Wastdale Head, are to be seen some exposures of rock of a peculiar character. This marks the south-western limit of the granophyre-intrusion in this district, and is probably another marginal forerunner, like those of Burtness and Bowness.

In hand-specimens this rock much resembles a rather coarse type of the granophyre, except as to its colour, which is more blue or grey, with a few conspicuous red felspar-crystals.

Under the microscope [4771] it is seen to consist of a rather coarse-grained aggregate of idiomorphic prisms of plagioclase-felspar, large irregular plates of orthoclase, and some interstitial quartz, with a considerable amount of ferromagnesian mineral. This includes some chlorite and epidote, but the bulk of it is hornblende, which is pale green or brownish and distinctly pleochroic; much of it shows uralitic character. A few long prismatic crystals now consist of chlorite; and both kinds of ferromagnesian mineral probably represent original augite. Large prisms of apatite and irregular crystals of magnetite are abundant.

The plagioclase-crystals show strong zonary banding, and the extinction-angle of the middle part is in some as high as 30°, while in the outer zones it is nearly straight. This shows that the felspar ranges from labradorite to oligoclase.

This rock seems to be another modification of the non-granophyric quartz-plagioclase-augite rock, which is so characteristic of this series; but it differs from the more ordinary examples in the

[1] Quart. Journ. Geol. Soc. vol. li (1895) p. 127.

possession of orthoclase, together with a rather basic plagioclase. This association suggests a comparison with the monzonite-family of Prof. Brögger, and the rock in question shows a distinct resemblance to his quartz-monzonites. Possibly it would be better to regard it as related to the banatites,[1] which are subalkaline rocks of the tonalite-group, containing typically a good deal of augite.

A little farther to the north-east, between Mecklin Wood and the farm known as Burnt House, is an interesting occurrence of a rather fine-textured grey rock, which is much fresher than is usual in this series. It occurs as an irregularly-shaped mass, about a third of a mile long and 100 yards broad at the most. It appears to be entirely surrounded by normal granophyre; but it is very near the margin of the latter, and is no doubt a forerunner like the last-described.

A slice of this rock [4772] is found to consist of plagioclase, biotite, hornblende, augite, and quartz, with accessory magnetite and apatite. The felspar is in the form of more or less ragged prisms possessing the habit characteristic of the diorites or dolerites; the extinction is nearly straight, showing that it is oligoclase. A little orthoclase is also present. Quartz is abundant, and its occurrence is interstitial, but not granophyric. The biotite is very fresh, deep brown in colour, and strongly pleochroic. Some of the most conspicuous elements in the rock are rather long narrow prisms of a mineral which is usually very pale green or nearly colourless, with a high index of refraction. Some crystals are non-pleochroic and have a wide extinction-angle, up to 45°: others are pleochroic, and have a narrow extinction-angle, usually below 10°, so that both augite and hornblende are present. The hornblende is probably secondary, of uralitic origin. These crystals are, no doubt, essentially the same as the needles of augite which are so characteristic of the margin of the granophyre-mass on the south-west of Seatallan and elsewhere.

The foregoing description shows that the affinities of this rock also are with the tonalites and banatites, rather than with the granites, since orthoclase is quite subordinate. It is essentially an augite-bearing quartz-mica diorite, which is practically the definition of a banatite.

On the south-west side of Mecklin Wood is a rock of a much more basic character. It forms a small mass, which is rather badly exposed just above the stream, and close to the wall bounding the wood. The mass is variable in character, but the bulk of it is a grey rock of moderately-coarse texture, showing well-marked tabular felspars, much dark mineral, and a little biotite and iron-pyrites.

In slices [4773] it is seen to be doleritic in structure, although many specimens are a good deal decomposed. It consists of zoned columnar felspars, ranging from labradorite to oligoclase, enclosed in typical ophitic fashion by large plates of a ferromagnesian mineral

[1] W. H. Weed & L. V. Pirsson, 20th Ann. Rep. U. S. Geol. Surv. pt. iii, 1898–99 (1900) p. 471; also Am. Journ. Sci. ser. 3, vol. 1 (1895) p. 467.

which is partly still fresh colourless augite, but for the most part converted into hornblende by uralitization. Some of the hornblende is actinolitic, in aggregates of long slender needles, but much of it is so well crystallized as to resemble an original constituent; it is distinctly pleochroic (bluish-green to pale yellowish-brown), and some patches have a very distinct blue colour. There are also a few flakes of a bright reddish-brown biotite, and abundant patches of ilmenite exhibiting very conspicuous bar-structure.

In the centre of this dolerite-intrusion is a large patch of a very coarse-grained gabbroid modification [4774], which shows crystals of felspar and uralitized augite measuring up to half an inch in length, and plates of ilmenite measuring up to 1 inch in diameter. Scattered through it are abundant flakes of red-brown biotite, measuring up to a quarter of an inch in diameter. Another noteworthy feature of this rock is the occurrence of what, at first sight, look like orbicular patches. A closer examination shows that these are partly-digested xenoliths, since every gradation can be traced—from obvious angular inclusions, up to more or less regular 'orbicles' measuring an inch or more in diameter.

No quartz was observed in any part of this dolerite-mass, and it is probably the most basic rock yet examined in this series.

IV. General Characters.

It appears from the foregoing descriptions, that this great series of intrusions comprises a large number of rock-types of variable character, but still showing many points of resemblance among themselves. Speaking generally, they may be regarded as products of the differentiation of one original magma; and this differentiation seems to have taken place in two stages, the deep-magmatic and laccolitic phases of Prof. Brögger. There has also occurred, to a certain extent, production of peculiar rock-types, as the result of the subsequent admixture of previously-differentiated partial magmas of the deep-magmatic series.

In both stages, the amount of basic rock produced by differentiation is small, in comparison with the bulk of acid rock; and this suggests that differentiation only continued for a short time, and the variations produced are not extreme.

If we consider the mineralogical composition of the magma as a whole, without regard to small basic modifications, it will be seen to consist of quartz, an intermediate plagioclase near to oligoclase, with subordinate orthoclase and perthite, and a rather small proportion of a ferromagnesian constituent (which crystallized either as biotite or augite, according to circumstances). Such a magma shows more resemblance to the tonalites than to the granites, although it is rather more acid than the typical tonalites, which usually contain about 66 per cent. of silica.[1] According to Clifton Ward[2] this rock contains about 71·5 per cent.

[1] H. Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 144.
[2] Quart. Journ. Geol. Soc. vol. xxxii (1876) p. 22.

The mineralogical composition is singularly uniform, and the more basic modifications consist essentially of the same minerals in different proportions, if we regard the biotite and augite as closely related, an assumption which seems justified by the evidence.

So far as structure is concerned, it is especially characterized by micrographic or micropegmatitic intergrowth, due to simultaneous crystallization of the quartz and felspar.

The earliest phase of intrusion is that of small masses of more basic character, which now occupy a marginal position; these may be described as ranging from dolerites and quartz-dolerites to a type in which the presence of a considerable proportion of orthoclase shows affinities to the quartz-monzonites of Prof. Brögger's classification. This was quickly followed by the intrusion of the main mass, while the earlier injections were in some cases still hot and partly liquid.

A noteworthy feature is the absence of any well-developed series of dykes of the more acid rocks. A few examples of dykes exist in the more northern part of the area, but those in the southern part seem to belong entirely to the Eskdale Granite.

In view of the abundance of garnet-bearing rocks in the central part of Lakeland, it is worthy of notice that I have not observed a single occurrence of garnet in any one of the very numerous specimens examined. The late E. E. Walker noted the occurrence of loose blocks of garnet-bearing rocks in Burtness-Combe Gill, and, chiefly on this evidence, stated his belief that the Buttermere-Ennerdale and Eskdale intrusions were derived from the same magma.[1] He did not see these rocks *in situ*, and I have observed nothing either there or elsewhere to confirm this idea: in fact, what evidence there is points the other way, although it must be admitted that it is chiefly negative evidence.

With regard to the age of the intrusion, I do not feel competent to express an opinion. The only evidence bearing on the point so far obtained, is the absence of cleavage on the north side of the Buttermere laccolite, which seems to show that the Skiddaw Slates on this side were protected from the influence of the great thrusts coming from the south-east, which so strongly cleaved them in other parts of the district. The intrusion was, therefore, previous to the great earth-movements of the later part of the Caledonian series. Whether it accompanied the Ordovician movements of the same series remains to be proved.

On reference to the map (fig. 1, p. 254), it will be seen that the Ennerdale and Eskdale intrusions come together at the foot of Wastwater. It might be expected, therefore, that this locality would possibly throw some light on the question of their relative ages. I have not been able to find any section showing both rocks in contact, since the probable line of junction is much covered by scree-material. Dr. A. R. Dwerryhouse, F.G.S., kindly informs me that he has been equally unsuccessful; a casual inspection seemed to show

[1] Quart. Journ. Geol. Soc. vol. lx (1904) pp. 84–85.

that the nearest exposures of the Eskdale Granite do not exhibit any marginal characters:—

'If, on further study of the neighbourhood of Easthwaite, this proves to be the case, it would point to one of two things: (*a*) Ennerdale rock intrusive in, and therefore later than, the granite; or (*b*) a faulted junction.'

Further work is required before anything definite can be said on the subject. I have much pleasure in expressing my thanks to Dr. Dwerryhouse for this interesting note.

V. Granophyric Structure.

As before stated, a detailed study of a large number of slices from different parts of these intrusions has shown that there exists a good deal of variation in different parts of the mass, and these variations seem to be arranged according to certain definite laws. From the field-evidence, it is clear that the intrusion, as a whole, forms a series of laccolites of varying size, which are sharply marked off one from the other. If we examine the distribution of the different rock-types in any one laccolite, we find a certain regularity of distribution, as follows:—Near the margin of the laccolite the rock shows a structure nearly approaching that of the normal acid plutonic rocks, with scarcely a trace of graphic intergrowth; a short distance from the margin, graphic structure begins to make itself manifest, at first of a very imperfect and irregular type; and, as we approach the centre of the visible mass, this intergrowth becomes continuously finer in texture, and of an increasingly-perfect micropegmatitic structure. In some specimens from near the head of Ennerdale Water in particular, this intergrowth becomes so intimate in character as to be scarcely capable of resolution by the ordinary powers of the microscope, and no doubt it also exists in a degree of fineness beyond the limits of visibility. Some of these finer types resemble certain forms of perthite, while others show a very strong likeness to photomicrographs of alloys of metals. This may also be expressed by saying that the structure in the inner parts of the laccolites approaches more and more closely to a molecular mixture of quartz and felspar, which may also be regarded as a solid solution.

The micropegmatite is of several different types. In one very common structure, large and more or less porphyritic crystals of felspar are surrounded by a sort of ring or fringe of micropegmatite, and the felspar of this fringe is in optical continuity with the large crystal. Structures of this sort seem to occur in connection with both orthoclase and plagioclase. Mr. Harker[1] has noted that, in some cases, crystals of plagioclase are surrounded by a narrow zone of orthoclase, and that by micropegmatite, and the felspar of the micropegmatite has the same orientation as this zone of orthoclase. However, this is not always the case, and many crystals of plagioclase are surrounded by a fringe of this nature without any intervening orthoclase. If the central crystal is small, the structure becomes somewhat spherulitic; but, unless a nucleus of this

[1] Quart. Journ. Geol. Soc. vol. li (1895) p. 128.

kind is present, the tendency to a centric arrangement of the quartz and felspar is not so marked as in many granophyres.

Micropegmatite also occurs very commonly in an interstitial manner, between more or less idiomorphic crystals of felspar or ferromagnesian minerals. Several different kinds of micropegmatitic structure may be distinguished, besides the fringing variety above mentioned: for instance the platy, the triangular, and the feathery types. Some of these apparent differences are doubtless due to the varying directions in which the sections are cut, and this almost certainly applies to the triangular and platy types. Some examples have a very strong resemblance to certain forms of perthitic structure; and, in some specimens, examination with a higher power shows that, what appear to be homogeneous and idiomorphic felspar-crystals under a low power, are in reality extremely fine-textured intergrowths of quartz and felspar.

It has been pointed out by many writers that mixtures of two substances, in a proportion approximating to the eutectic ratio, frequently show structures resembling micropegmatite; and it is now believed that ordinary micropegmatite is a eutectic of quartz and felspar. According to Prof. Vogt,[1] the eutectic ratio for quartz and felspar is 26 : 74; his figures apparently apply to orthoclase, and it is possible that the ratios may be slightly different for plagioclase.

The eutectic mixture would be the last to crystallize; and so we should naturally expect to find micropegmatite in the inner parts of the mass, which remain longest in the liquid state.

It appears, therefore, that in the case of the Ennerdale Granophyre the conditions of cooling were such that crystallization went on from without inwards, leading to the successive supersaturation of the magma for the different constituents, according to the principles laid down by Prof. Morosewicz and others. The course of crystallization was such that the still molten residue approximated more and more closely to the composition of the eutectic, and therefore finally solidified as micropegmatite.

This is in accordance with the idea put forward by Prof. Morosewicz[2] and Dr. Teall.[3] These processes, however, seem to be controlled by other factors, such as rate of cooling and pressure. The true deep-seated plutonic rocks, which have consolidated under a great thickness of rock-cover, do not show much graphic structure. On the other hand, this structure is very well-marked in many rocks which appear, from independent evidence, to have consolidated under a comparatively-thin covering, although occurring in large masses: as, for example, many of the Tertiary intrusions of North-Western Europe. This suggests that pressure is probably an important factor in the case, and that pressure alone, or pressure and rate of cooling conjointly, determine in any particular instance whether an acid magma shall crystallize as a granite or a granophyre.

[1] 'Die Silikatschmelzlösungen' pts. i & ii, Vidensk. Selsk. Skrifter, 1903, no. 8 & *ibid.* 1904, no. 1; see also review by A. H. in Geol. Mag. 1905, p. 132.

[2] Tschermak's Min. Petr. Mitth. n. s. vol. xviii (1899) p. 1.

[3] Presidential Address, Quart. Journ. Geol. Soc. vol. lvii (1901) p. lxxv.

VI. Summary and Conclusion.

From the facts put forward in this paper, it may be concluded that the Buttermere-Ennerdale intrusion is an excellent example of an acid magma which has crystallized under the peculiar set of conditions that give rise to a very perfect development of granophyric structure. These conditions are probably, to a certain extent, intermediate between those of the plutonic and the true hypabyssal rocks.

Besides the normal acid rock which composes the bulk of the intrusions, there are some marginal patches of a more basic character, showing obvious genetic relationship, and slightly earlier in point of time than the intrusion of the acid rock. These basic forerunners afford evidence of partial differentiation of the magma before intrusion, an example of Prof. Brögger's deep-magmatic differentiation. There is also some slight indication of laccolitic differentiation.

Considered as a whole, the petrographical character of the magma shows closer affinity to the tonalite-group than to the true granites, although it is somewhat more acid than the majority of the tonalites. The more basic types include dolerites, quartz-dolerites, and a rock-type intermediate between quartz-dolerites and granophyres, for which no satisfactory name seems to exist. There is also a development of peculiar rock-types, as the result of the re-mixing of previously-differentiated partial magmas of an acid and a basic character respectively.

A study of the distribution of different types of granophyric structure shows a certain regularity of arrangement, and an attempt is made to reconcile these with known physical laws, especially with reference to eutectics; and it is concluded that the structure is the result of crystallization under conditions intermediate between those which produce typical plutonic and hypabyssal rocks.

It was originally my intention to deal also with the study of the very interesting metamorphism brought about in the Skiddaw Slates by these intrusions, but pressure of teaching work during the last two years has prevented me from carrying out this intention. I have collected a large amount of material, and hope soon to be able to continue the investigation.

In conclusion, I have much pleasure in expressing my hearty thanks to Dr. Marr for much kind help and encouragement, without which the work would have been impossible, and also to Mr. Alfred Harker for much help in the petrological part of the work. My best thanks are due to Mr. W. G. Fearnsides, M.A., F.G.S., for his kindness in taking the photographs for illustrations. I am also greatly indebted to Mr. J. P. Millington, Mr. Bernard Smith, and Mr. B. Schön for much pleasant companionship and help in the field.

EXPLANATION OF PLATES XXVII & XXVIII.

[All the figures are magnified 21·5 diameters.]

Plate XXVII.

Fig. 1. [4750] Granitic margin of the Buttermere laccolite, near Scale Force, showing interstitial quartz.
2. [4748] The same, showing idiomorphic plagioclase.

Plate XXVIII.

Fig. 1. [4755] Granophyre, Boathow Crag, Ennerdale, half a mile from the margin, showing micropegmatite of a medium degree of fineness.
2. [4759] Granophyre, Sail Hills, Ennerdale, $1\frac{1}{2}$ miles from the margin, showing micropegmatite of very fine texture.

Discussion.

The President regretted the absence of the Author, owing to illness. He welcomed the very interesting paper, and congratulated himself that he had suggested that the Author should undertake the study of these rocks. The Author had referred to Clifton Ward's work—work which was naturally acknowledged by all who had subsequently worked in the district. In Ward's time the study of differentiation of magmas had not been extensively followed, and the Author had taken advantage of work which had been done in this direction, with very good results. He had been well advised in alluding but briefly to the relationship between the granophyre and the 'tectonics' of the district. The paper was really the first part of a study of the area, the second part of which would deal with the metamorphism.

Dr. C. G. Cullis said that he had been interested to hear that, from a consideration of the granophyric structures of the mass, the Author had arrived at the conclusion that it must have been formed under conditions intermediate between the plutonic and the hypabyssal; and it had occurred to him that the accuracy of that conclusion might, to some extent, be tested in an interesting manner. The Buttermere and Ennerdale Granophyre was one of at least three masses of acid igneous rocks which, in that region of the Lake District, had been intruded into or against the Skiddaw Slate. The other two he had in mind were the Threlkeld (St. John's) Microgranite and the Skiddaw Granite. Of these the latter had consolidated under typical plutonic conditions, the former under hypabyssal. In the case of the plutonic rock, the contact-metamorphic effects produced in the Skiddaw Slate were of the most striking character, the sediments having completely recrystallized for some hundreds of feet, at least, from the junction; but in that of the hypabyssal rock the effects had been very slight, being limited to the hardening of the slate at the junction, so as to form a selvage not more than a few inches thick. If the Buttermere and Ennerdale Granophyre had indeed been formed under conditions intermediate between the plutonic and the hypabyssal, it might

reasonably be expected that the contact-metamorphic effects produced by it would also be of an intermediate character, and he suggested that a comparison of the three cases might perhaps afford evidence confirming the Author's views.

Mr. J. V. Elsden drew attention to the fact that the Author's interesting conclusions with regard to the influence of pressure upon the formation of a granophyric structure seemed to be opposed to those of Prof. Vogt, who, after an exhaustive study of analyses by Lagorio and others, had strongly expressed the opinion that even considerable differences in the depth at which consolidation takes place can have very little effect upon the eutectic composition. With regard to the occurrence of micropegmatite in the interior portion of the mass, this was what would be expected of the product of the final consolidation of the mother-liquor. The rule, however, did not appear to be universal, for an instance had come before the speaker's notice, in the enstatite-diorite of Carnedd Lleithr, near St. David's, in which the only pronounced micropegmatite seemed to occur quite on the extreme margin of the intrusion.

Prof. Watts expressed his regret at the Author's absence and the cause of it. He remarked that Mr. Fearnsides was more or less responsible for the singularly-perfect photographs shown on the screen, which enabled hearers to follow with ease the necessarily somewhat technical descriptions embodied in the paper. Dr. Teall had been the first in Britain to direct attention to the part played by eutectics in rock-magmas, and had tabulated analyses of numerous micropegmatites showing that they had a practically-uniform composition. His conclusions had been driven home by all the most recent work on the crystallization of alloys.

Mr. W. G. Fearnsides, in the absence of the Author and in reply to Dr. Cullis, explained that the question of the metamorphism produced by the granophyre was still *sub judice* and was being worked at by the Author. He commented upon the enormous extent of country which must be covered in the course of such an investigation; but thought that, so far as the Author had gone, the metamorphism was certainly found to be of a type intermediate between that around the Threlkeld Micr順granite and that of the Skiddaw-Granite aureole. As a further example of a tonalitic granophyre, in which the centre of the mass was finer-grained and more definitely and more minutely micropegmatitic than the margin, he would mention the rock-mass which was variously known as the Tan-y-grisiau Syenite and the Ffestiniog Granite: this is intrusive into the slates and flags which immediately underlie the Ordovician Volcanic Series of North Wales. In this mass also there is a tendency, for certain parts of the marginal granitic or granulitic portion, to lose its felspar and pass into a sort of secondary greisen.

13. *The* CARBONIFEROUS ROCKS *at* RUSH (*County* DUBLIN). By CHARLES ALFRED MATLEY, D.Sc., F.G.S. *With an* ACCOUNT *of the* FAUNAL SUCCESSION *and* CORRELATION. By ARTHUR VAUGHAN, B.A., D.Sc., F.G.S. (Read December 20th, 1905.)

[PLATES XXIX & XXX—FOSSILS.]

CONTENTS.

I. INTRODUCTION. [C. A. M.]

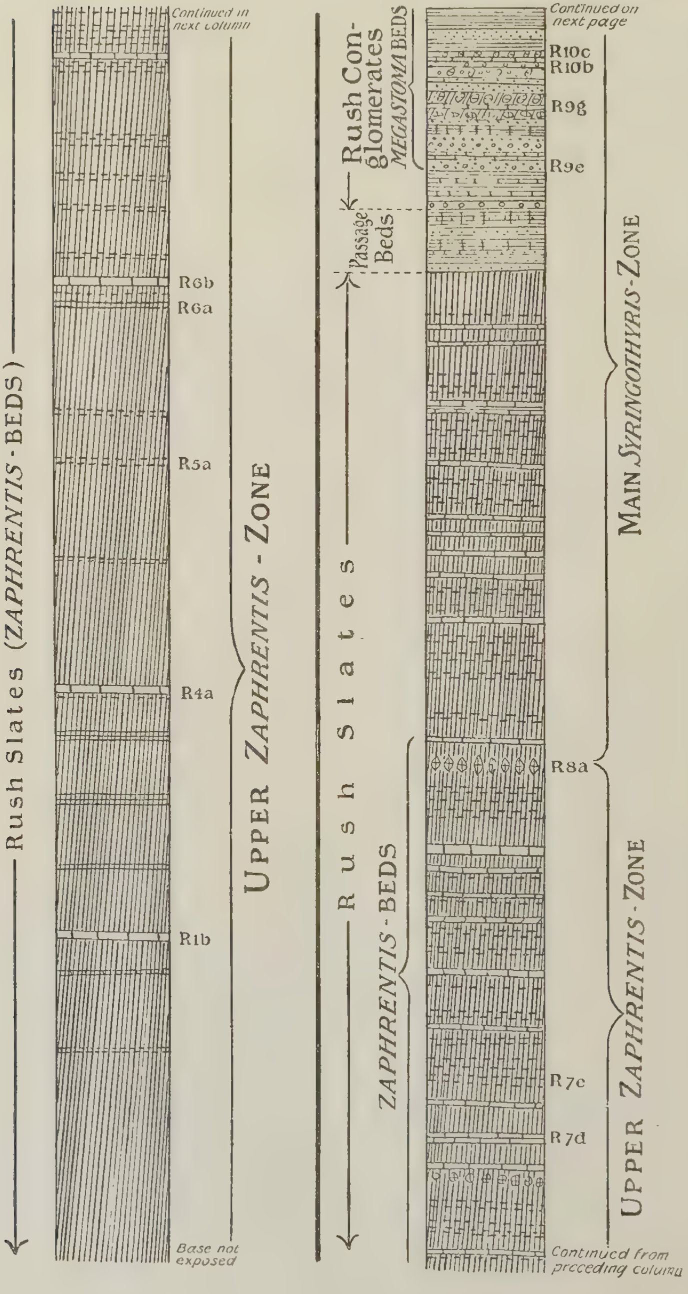
ALTHOUGH Carboniferous rocks form the rock-floor of the greater portion of the County of Dublin, they are so much concealed inland by Glacial Drift as to render their structure and relationships usually obscure. On the coast, however, they crop out in several very good sections, especially near Malahide, about 4 miles north of Dublin Bay, and at Rush, about 6 miles still farther north. The latter is the more extensive and interesting of these two.

From the shore south of Rush village, extending northward past Loughshinny to within a mile of Skerries—a distance in all of about 5 miles — the Lower Carboniferous rocks are splendidly exposed: the outcrops being only interrupted occasionally, where the shore is covered by sand, or the Glacial Drift descends to sea-level. At the suggestion of Mr. G. W. Lamplugh, F.R.S., and tempted by tho interesting character of the rocks themselves, I was induced (during a temporary residence in Ireland) to make a detailed examination of these beds. In order to understand the coast-section in full detail, a horizontal section of the beds, as shown in the cliffs and along the rocky shore, has been prepared for the whole distance on the scale of 1 inch to 10 feet.[1] As, however, fossils have up to the present been collected only from the rocks near Rush, that is to say at the southern end of the line of section, the present communication will be restricted to that part of the area;

[1] The section does not pretend to absolute accuracy. The base-line has been roughly measured on the ground with a 10-foot string weighted at one end by a stone, the details of the exposure being sketched in at the same time. But the scale is sufficient to allow of all the important beds being shown and the structure being recorded in considerable detail, while the horizons from which the fossils have been obtained are thus fixed with much precision. The thicknesses of beds, as given in the following pages, are calculated from the section and checked with the 25-inch map. The margin of error should, therefore, not exceed 10 per cent.

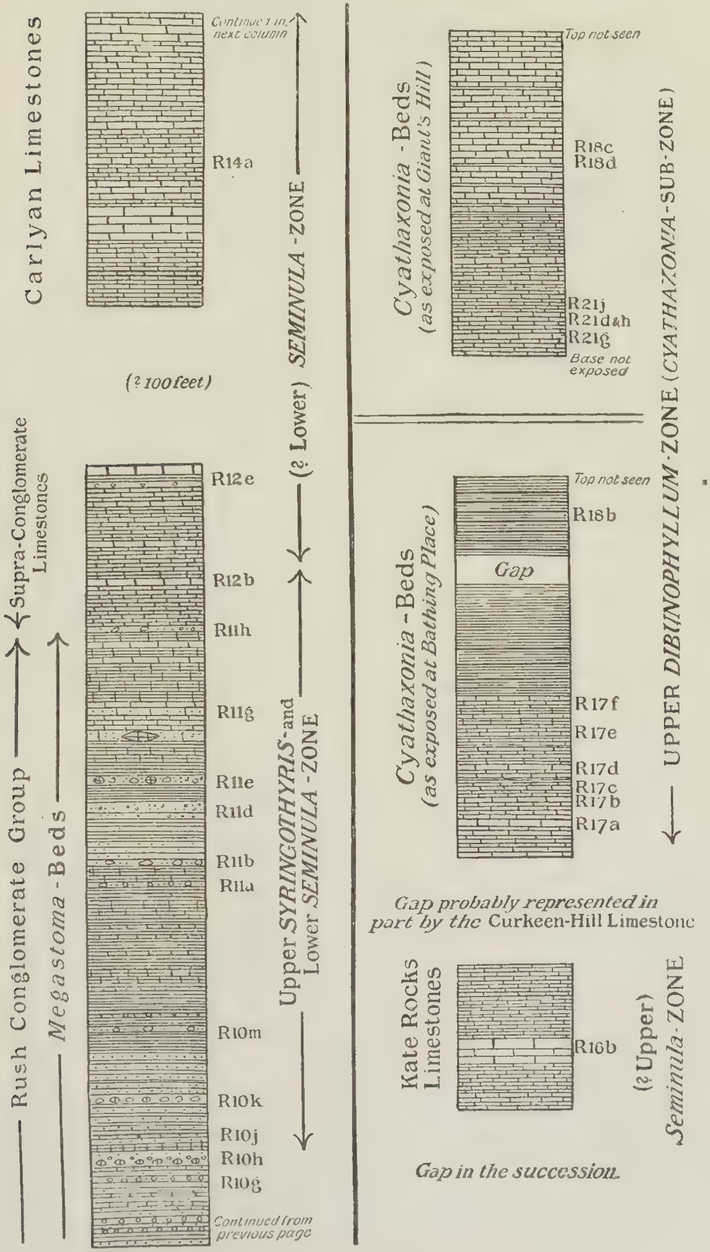
Fig. 1.—*Vertical section of the Carboniferous rocks*

[The notation on the right of the section refers to fossiliferous



at Rush, on the scale of 120 feet to the inch.

beds the fauna of which is enumerated in the faunal lists, pp. 295–99.]



but I hope to present an account of the remainder of the section in a future paper.

The description of these beds in the Explanatory Memoir of the Geological Survey of Ireland (Sheets 102 & 112)[1] seems to be the only detailed account that has hitherto been published. In G. V. Du Noyer's section on p. 62 of that memoir, all the beds at the Rush end of the coast-section are lettered *d 4*, except a small patch of black shale south of Brook's End which is marked *d 5*, and this notation agrees with that in the 1-inch Geological Survey-map (Sheet 102, revised 1901); but *d 5* is absent from the index of the map, and the beds so marked are coloured as though they were the '*d 3* & *d 4* (Millstone Grit & Yoredale Beds)' of the index; while, to add to the difficulty of reading the map, the *d 4* areas are coloured to correspond with the '*d 2* (Calp)' of the index. It may be presumed, however, that the colouring, and not the lettering, indicates the current opinion of the officers of the Survey as to the age of the beds at Rush.[2]

The term Calp is used by the Geological Survey to include in this particular area both the true Calp (Middle Limestone) and the Upper Limestone, as the latter is believed to have taken on a 'calpy' character here, and thereby to have become indistinguishable lithologically from the Middle Limestone.

Palæontology has hitherto been of little service in separating the beds, but, as will be shown below, Dr. Vaughan has now ascertained, from an examination of the fossils of the Rush sequence, that the same faunal succession is to be found, with slight modification, on both sides of St. George's Channel, and he has been able to subdivide the beds into palæontological zones corresponding with those that he has already described from England and Wales.

II. General Structure and Sequence. [C. A. M.]

The Carboniferous beds of Rush are separated on the south, from the Ordovician and Old-Red-Sandstone inlier of Portraine[3] by the mouth of an estuary $1\frac{1}{2}$ miles wide, and on the south-east, from the somewhat similar rocks of Lambay Island[3] by $2\frac{1}{2}$ miles of sea.

[1] 2nd ed. (1875) pp. 61-66.

[2] On my making enquiries of Prof. Grenville Cole, F.G.S., who now has charge of the Irish Geological Survey, he has been good enough to explain how the confusion between lettering and colouring has come about. It appears that, when Sheet 102 was originally issued in 1859, certain outliers of 'Coal-Measures' (the *Posidonomya*-Beds) were coloured on it in the Rush area. When revised about 1875 the 'Calp' anticlinals along the coast were inserted, but without the removal of the letter *d 4*. In the index the Calp is marked *d 3* & *d 4*, and the Upper Limestone *d 4* also. At a later revision the 'Coal-Measure' area was coloured 'Millstone Grit & Yoredale,' and some of the *d 5* marks were altered to *d 3*, the margin showing 'Millstone Grit & Yoredale Beds' as *d 3* & *d 4*. But *d 4* was allowed to remain on the Calp anticlinals, which now should have been lettered *d 2*. Prof. Cole adds that it is intended to rectify the discrepancies in the map at an early date.

[3] For an account of the rocks of Portraine and Lambay Island see C. I. Gardiner & S. H. Reynolds, Quart. Journ. Geol. Soc. vol. liii (1897) p. 520, & vol. liv (1898) p. 135.

To the north, at Skerries and at Shenick's Island, Llandovery Beds with a small patch of Old Red Sandstone are also found; consequently, the general structure of the Carboniferous rocks between Rush and Skerries, although complicated by much folding and by some faulting, must be that of a syncline.

There is a general upward succession of the beds exposed near Rush, as they are traced from south to north; and the sequence, in descending order, is as follows:—

Stratigraphical Zones.		Thickness in feet.	Palæontological Zones.
Cyathaxonia-Beds.	Limestones, sometimes cherty, containing chert-seams, interstratified with shale, and decomposed locally into decalcified beds.	200	Upper *Dibunophyllum*-Zone (*Cyathaxonia*-Subzone).
[Gap, probably occupied in part by the horizon of the limestone of Curkeen Hill, mentioned on p. 294.		?	Upper *Dibunophyllum*-Zone.]
Kate-Rocks Limestones.	Thickly-bedded limestone, underlain and overlain by thin calcareous dark shales and thin limestones. Some chert-seams.	90	(? Upper) *Seminula*-Zone.
[Gap]		?	
Carlyan Limestones.	Thickly- and thinly-bedded dark-grey limestones, occasionally pebbly, with calcareous flaggy beds.	180	(? Lower) *Seminula*-Zone.
[Gap		?100	Gap]
Supra-Conglomerate Limestones.	Flaggy limestones sometimes pebbly, with partings of black shale.	100	*Feet.* 70 Lower *Seminula*-Zone. 30 } Upper *Syringothyris* & Lower *Seminula*-Zone.
Rush Conglomerate Group.	Conglomerates, sometimes very coarse, usually having a limestone-matrix and interstratified with shales and calcareous sandy flags.	500	330 } Upper *Syringothyris* & Lower *Seminula*-Zone. 170 } The Main *Syringothyris*-Zone.
Passage-Beds.	Calcareous sandy and shaly beds.	40	40 } The Main *Syringothyris*-Zone.
Rush Slates.	Black slates, often calcareous and nodular, with occasional limestone-bands & lenticles.	1380	300 } The Main *Syringothyris*-Zone. 1080 Upper *Zaphrentis*-Zone.
	(Base not seen.)		

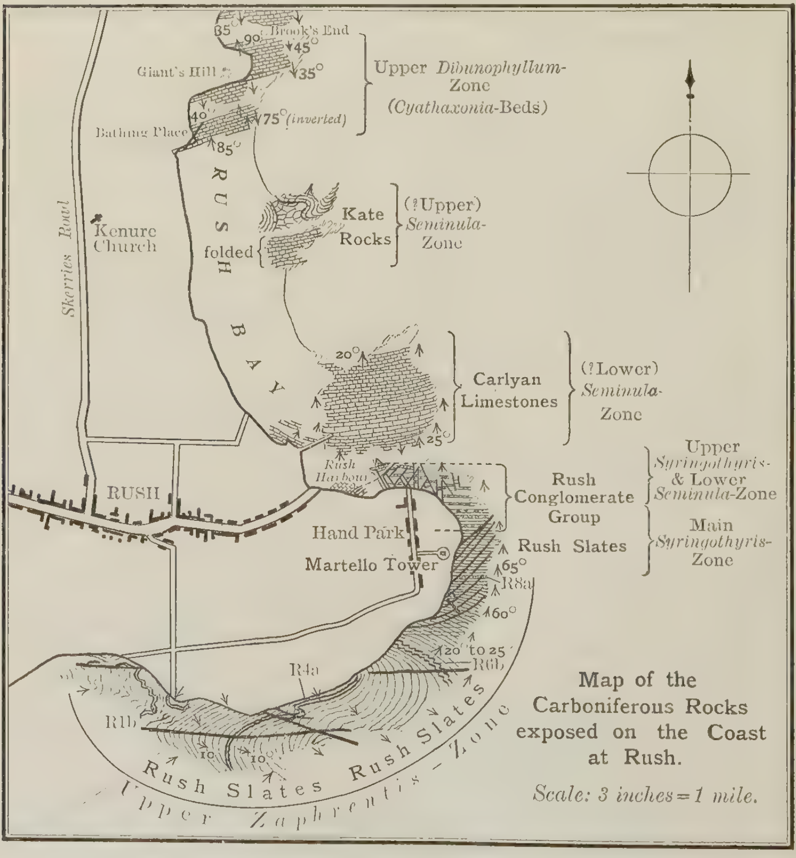
The rocks will now be described in ascending order.

III. Description of the Rocks. [C. A. M.]

(*a*) The Rush Slates and Passage-Beds (*Zaphrentis*-Beds).

The Rush Slates are well exposed, when the tide is out, on the shore south and south-east of Rush. They consist of black and dark-grey, well-cleaved argillaceous slates, with numerous bands of dark, less perfectly-cleaved, calcareous slate, sometimes containing nodules

Fig. 2.



of impure limestone or intercalated with occasional well-defined bands of moderately-pure limestone. Their base is not exposed. The lowest beds visible are seen emerging from the sandy beach at the western extremity of the rocky shore; and there is a general upward succession as the beds are followed along the coast, first eastward and then northward towards Rush Harbour, before

reaching which place they are seen to pass upwards into the Rush Conglomerates. The strike of the rocks on the southern shore (see fig. 2, p. 280) forms a sigmoidal curve, and the beds are arranged in an elliptical basin followed on the north by an elliptical dome, the long axis of the basin running in an approximately east-and-west direction and having an easterly pitch. The principal axis of the folding corresponds with the strike of the cleavage.

At the western end of the outcrop, in the neighbourhood of the well called Tobberkilleen, and at a horizon about 200 feet above the lowest visible bed, there is a band of limestone [R 1 *b*][1] containing a few fossils. It sometimes stands out from the neighbouring slates in small dome-like elevations, and can be traced as a broken and twisted band for some distance, until it becomes lost in a mass of nodules which seem to be the result of the disintegration of the limestone by the forces that produced the cleavage. A second well-defined limestone-band [R 4 *a*] occurs some 150 feet above the first, and a third [R 6 *b*] is found about 250 feet above the second. Their peculiar outcrop will be described later.

These lower beds of the Rush Slates (that is, up to the third limestone-band R 6 *b*) have a curved strike and a rather low dip, usually from 10° to 20°. They form a low rocky shore, almost wholly below high-water mark, the argillaceous slates having a rather smooth aspect, while the more calcareous zones weather with ragged edges. To make out their general structure is an easy task; but the details give much more trouble, owing to the frequent obscuration of the bedding by cleavage, to the growths of seaweed on the rocks, and to the monotonous character of the beds themselves. Several fault-lines can, however, be traced in the slates; but the fractures all appear to have a very slight throw, and do not affect the general stratigraphy.

Near the third limestone [R 6 *b*] the coast-line changes in direction, and turns northward. This change is accompanied by a rapid increase in the dip of the beds up to 60° or 65°, and at the same time the curved strike straightens out so that the beds run very regularly in an east-and-west direction. This change in strike is naturally accompanied by some displacement of the beds, and accordingly a number of sub-parallel faults, with some connecting fractures, can be seen here running in a direction a little to the north of north-east; but their throw is insignificant, varying from a few inches to a few feet. A large nest of calcite, on the shore near high-water mark, marks the intersection of two of these faults. The strike of the beds is now at right-angles to the coast-line, and the scenic effect here is quite different from that of the beds on the southern shore. The rocks now present a series of sharp ridges running out to sea, steeply inclined on the northern or dip-face, and but slightly broken by the small cross-faults just mentioned. The ridges are separated from each other by sharply defined gullies, where

[1] The notation R 1 *b*, R 4 *a*, etc. refers to the horizons as shown in the vertical and horizontal sections, and catalogued in the faunal lists.

sea-erosion has channelled out the softer and more argillaceous beds (see fig. 3, below). It should be noticed that the erosive action of the sea here follows the bedding-, not the cleavage-planes, this being due to the fact that while the soft argillaceous beds are still well-cleaved, the harder calcareous bands are only imperfectly fissile in the cleavage-direction.

Fig. 3.—*Upper Rush Slates, on the shore south of Rush Harbour, looking eastward.*

[The beds dip steeply northward, while the cleavage dips steeply in the opposite direction. The strike is east and west. The softer argillaceous beds are eroded, leaving the calcareous beds standing out as ridges.]

The upper slates above the third limestone-band [R 6 *b*] are more calcareous than those below. Nodules and lenticles of impure limestone are found in them at many horizons; while seams and beds of purer limestone which have resisted cleavage are occasionally intercalated. About 480 feet above R 6 *b* is a prominent bed [R 8 *a*], some 6 feet thick, composed of lenticles of limestone (one of them 5 feet thick) embedded in a black slaty matrix. The slates continue for about 300 feet above this zone, and then pass, after about 40 feet of Passage-Beds, into the Rush Conglomerates. Pebbles in the upper portion of the Rush Slates, although decidedly rare, are occasionally to be found, and there is a 1-inch seam [R 9 *a*] of fossiliferous limestone containing numerous tiny quartz-pebbles as low down as 120 feet below the Passage-Beds.

The Passage-Beds, about 40 feet thick, are intermediate in character between the Rush Slates and the Rush Conglomerates.

They consist of black shales, sometimes calcareous, interstratified with thin flaggy bands of sandy limestone containing quartz-pebbles and rock-fragments, for the most part of small size. Cleavage is beginning to die out, and is weak, except in the basal beds.

Fossils have been collected from various horizons in the Rush Slates, and those sufficiently well preserved to be identified are recorded on a later page (p. 295). The lowest 200 feet have not yet yielded fossils; but they may be provisionally grouped in the same zone as the overlying beds. The beds between R 1 *b* and R 8 *a* seem to belong to the 'Upper *Zaphrentis*-Zone ($Z\,2$–γ)' of Dr. Vaughan, their upper portion (R 6 *b* to R 8 *a*) containing a typical 'γ' fauna. From R 8 *a* into the overlying conglomerates the beds are assigned to the 'Main *Syringothyris*-Zone' (C). The typical fossil of all these beds is *Zaphrentis* cf. *Phillipsi*, Edw. & H.

Before passing on to the description of the Rush Conglomerates, the more striking effects of compression on the Rush Slates ought to be noticed. The shallow basin of Lower Slates on the southern shore is crossed, as already stated, by cleavage striking nearly east-and-west, with the result that over the larger part of the exposures there is a marked discordance between bedding- and cleavage-strikes. Owing to the fact that the shales have yielded to compression more than the limestone-bands, the latter have usually been crumpled at right-angles to the cleavage-strike, in order to reduce their horizontal extent. Fig. 4 (p. 284) shows the lobe-like extensions which this oblique direction of compression produces on the outcrop. It will be noticed that the detailed folding of the bed is quite discordant with the general dip. Occasionally the folding is so pronounced as to produce a slight inversion of the bed, and the concave surfaces are puckered into minute corrugations. The crumpling dies out in the slates in a very few feet vertically above and below the crumpled bed. From a measurement, necessarily rough, of the surface of the limestone taken across the folding, it appears that 5 feet of limestone corresponds to about 3 feet of slate; and, as this would represent the minimum compression, we may infer that the slates have been reduced by nearly one-half their original extent across the cleavage-strike. One effect of the compression on the slates is that their thickness will be found to vary if measured in different directions, being least where the bedding-strike coincides with the cleavage-strike, and greatest where the two strikes are at right-angles.[1]

The augen-like nodules of impure limestone which are common in

[1] The peculiar stratigraphical features of these limestone-bands, although occurring on a small scale and in other ways exhibiting considerable differences, are recommended to the notice of geologists interested in the much-debated structures of limestone-knolls. Substitute for the thin bands in the Rush Slates a massive but flexible limestone lying between masses of more compressible strata, and for the overlying Rush Conglomerates substitute a thick mass of Millstone Grit, and subject the whole to powerful compression: then one may expect as a result, that the surface of the limestone will be thrown into folds which would be locally unconformable to the adjacent strata, and that about the junction some brecciation may be looked for.

the slates are so arranged, that their long axes lie in the direction of cleavage. Usually they are imperfectly cleaved, and their edges are tailed out into thin plates. Several adjacent nodules at one spot were found to measure as much as 36, 40, and 63 inches respectively along the cleavage, though none of them exceed 7 inches across the cleavage. They are clearly deformed by the compression, but their length in comparison with their width is so great that it is difficult to regard them as of ordinary concretionary origin. Although it would be rash to dogmatize in the case of such rocks as limestones, in which concretionary structure is so common, and is no doubt the origin of many of the nodules at Rush, I am convinced that in numerous instances the lumps of limestone lying in the Rush Slates were once portions of bands that have been broken up by movement, which has squeezed the soft shale of adjacent beds into the interstices between the separated fragments. A reference to fig. 4 shows that a mass of nodules is associated with the limestone-band R 4 *a*, and this the writer regards as a broken-up part of the band lying in a synclinal fold. Other instances occur of thin limestone-bands in the slates, slightly oblique to the cleavage, being converted into a connected string of phacoids elongated along the cleavage-planes. In the higher part of the slates, where the dip is high, the limestones break up into phacoids which are, however, practically continuous one with the other.

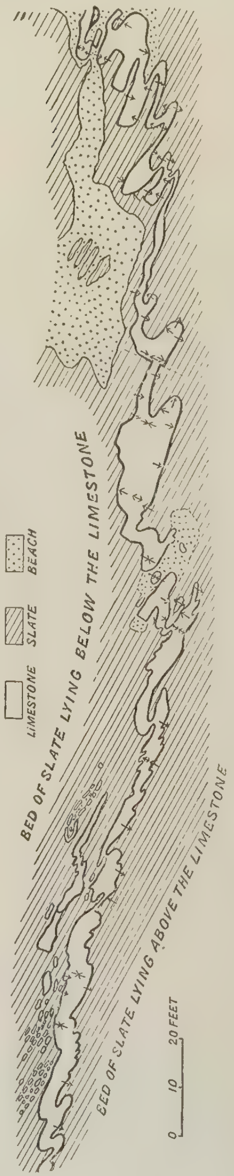


Fig. 4.—*Plan of a limestone-band [R 4 a] in the Rush Slates, showing the effect of oblique cleavage-strike on the outcrop of the limestone.*

(*b*) The Rush Conglomerate-Group (*Megastoma*-Beds).

These consist of numerous beds of very regularly-stratified conglomerate, occurring singly or several together, and separated by narrow or wide intervals of sandy calcareous flags, sandy and pebbly limestone, and laminated shale.

FIG. 1. × 21.5

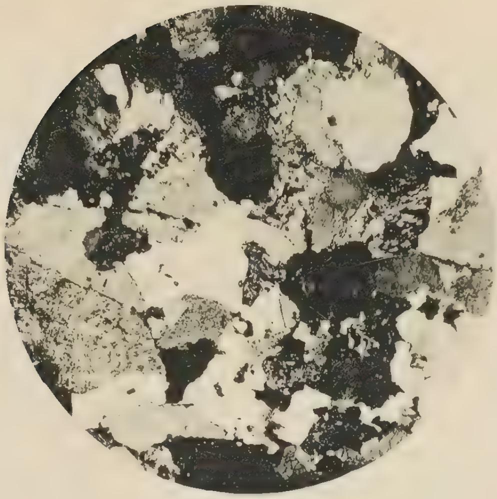


FIG. 2. × 21.5

GRANITIC MARGIN OF THE BUTTERMERE LACCOLITE.

W. G. F., Photomicro.

Bemrose, Collo.

Fig. 1. × 21.5

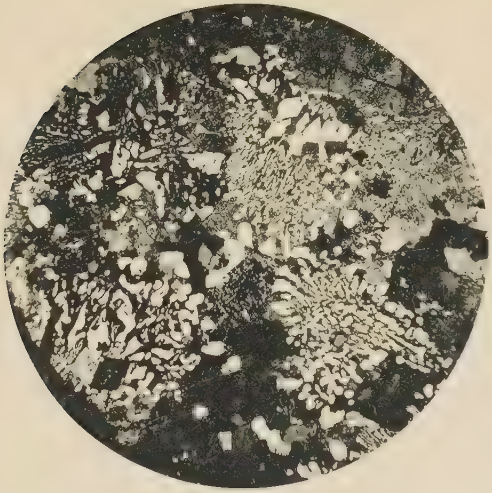
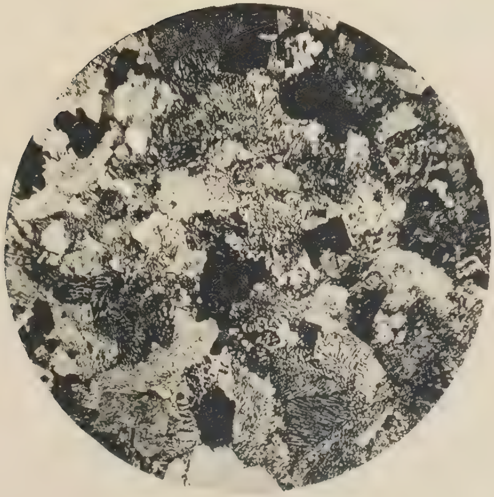


Fig. 2. × 21.5



ENNERDALE GRANOPHYRE.

W. G. F., Photomicro. *Bemrose, Collo.*

The most conspicuous of the conglomeratic bands usually vary from 2 to 4 feet in width, while one [R 10 *h*] is nearly 12 feet thick. They dip steadily northward in conformity with the underlying beds at angles of 50° to 65°, and they are broken by numerous small faults, which are well displayed on the shore close to Rush Harbour (see fig. 6, p. 287). The included pebbles are, as a rule, fairly well water-worn, their angles and frequently their whole surface being rounded. In some bands the inclusions are small, not exceeding the size of a hazel-nut; in others they are considerably larger; while in some beds very large pebbles abound, frequently exceeding 1 foot in length. One pebble measured 26 × 22 inches, another 32 × 14 × 10 inches, and even larger ones could probably be found by more exhaustive search. They consist for the most part of white quartz, grits and slates of various colours, andesitic rocks, and limestone, and are usually embedded in a limestone-matrix in which corals, brachiopods, crinoid-fragments, and other fossils are not infrequent.

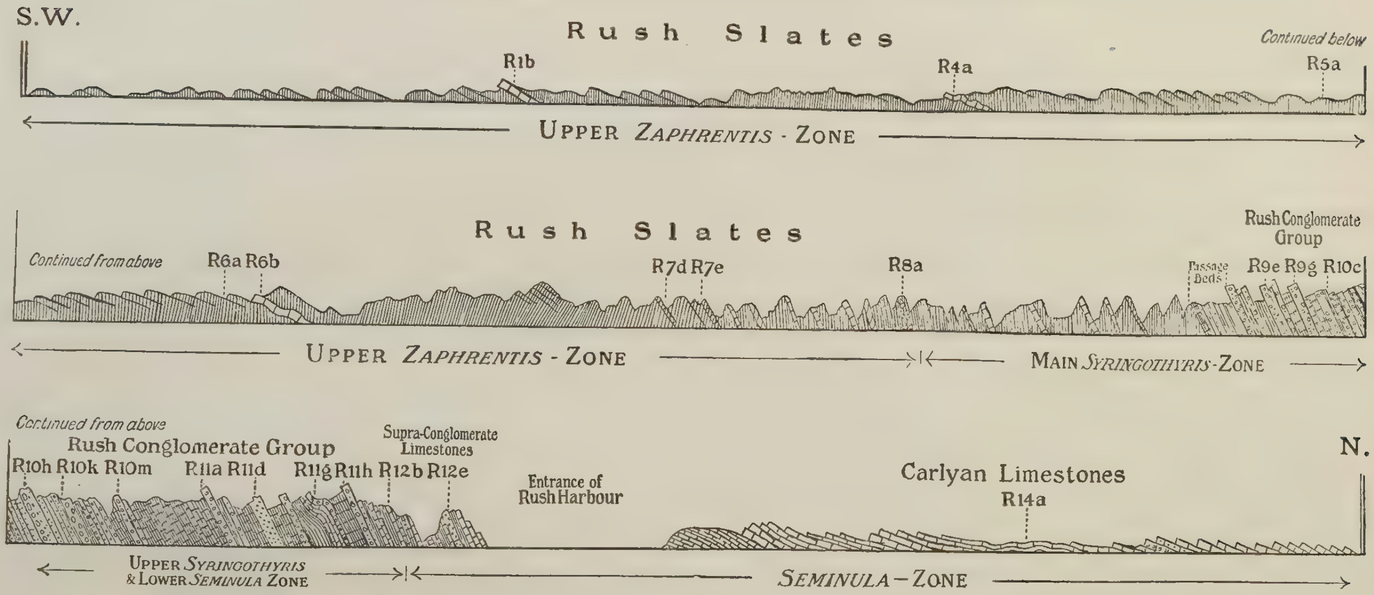
With the exception of the limestone-inclusions, the origin of the pebbles is easily referred to the Ordovician and Silurian rocks of the neighbourhood. Such rocks are now found *in situ* at Portraine on the south, and near Skerries on the north. The limestone-pebbles, which predominate largely in some of the beds, present more difficulty. Although it is possible that a few of them may be derived from the Ordovician limestone of Portraine, the very great majority are undoubtedly of Carboniferous-Limestone age. Now, the Rush Conglomerates and the Pendine Conglomerate of South Wales are shown, by the zonal work of Dr. Vaughan, to be on the same horizon (*Syringothyris*-Zone). The latter conglomerate also contains Carboniferous-Limestone pebbles, which are thought, from fossils found in them, to have 'been derived from a horizon probably not higher than a low part of the *Zaphrentis*-Zone.'[1] To regard the Rush Conglomerate-Group, like the Pendine Conglomerate, as an 'intra-formational conglomerate'[2] in respect to its limestone-pebbles, seems to be on the whole the most satisfactory explanation of the presence of these inclusions. The few fossils found in them have, as yet, yielded no clear evidence as to the horizon from which they have been derived; but, so far as it goes, it implies very little or no difference of age. The occasional presence of small pebbles in these inclusions suggests, however, that they may be of contemporaneous or almost contemporaneous horizon, or may in some cases have been formed *in situ*. One limestone-inclusion, occurring as a lenticle 7 feet long by $4\frac{1}{2}$ feet wide, in a bed of very pebbly limestone [R 11 *f*], must certainly have been formed in place.

The conglomerates have greatly interfered with the action of the cleavage that has had so marked an effect on the Rush Slates. Not only are they quite unaffected by it themselves, but they have almost completely protected the beds intercalated in them, even the

[1] 'Summary of Progress of the Geological Survey for 1904' Mem. Geol. Surv. 1905, p. 44.

[2] *Cf.* C. D. Walcott, 'Palæozoic Intra-Formational Conglomerates' Bull. Geol. Soc. Amer. vol. v (1894) pp. 191–98.

Fig. 5.—*Horizontal section through the Rush Slates to the Carlyan Limestones.*



[Horizontal scale : 25 inches = 1 mile. The vertical scale and the thickness of individual beds are exaggerated.]

Fig. 6.—*Sketch-map showing the faulting of the Rush Conglomerates at Rush Harbour.*

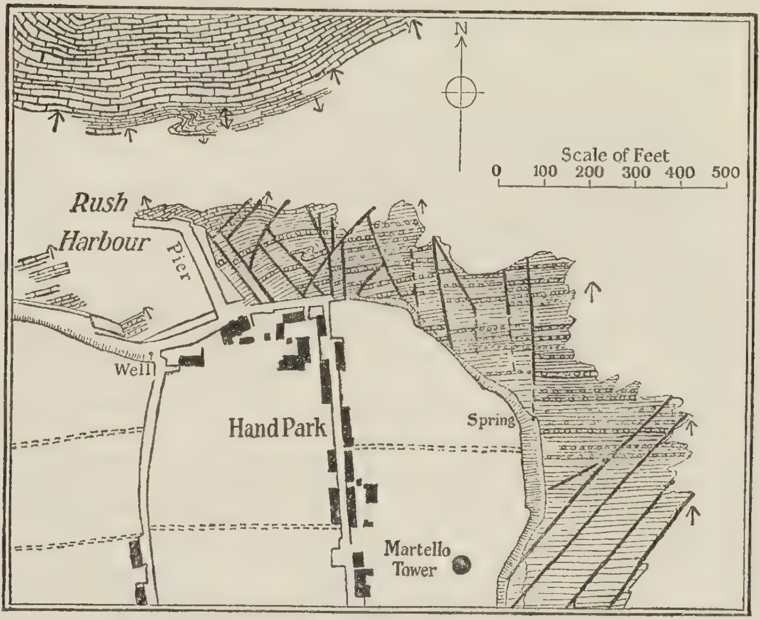


Fig. 7.—*Rush Conglomerates, near Rush Harbour, showing the size of the inclusions of Ordovician (or Silurian) rocks in the coarser conglomerate-bands (Upper* Syringothyris- *and Lower* Seminula-*zone).*

fine shales being cleaved but occasionally, and then imperfectly. There is, moreover, very little good cleavage in any of the beds to the north of the Conglomerate-Group[1] for some distance, and then only on a small scale.

Correlating the Rush Conglomerate-Group on the evidence of the fossils, Dr. Vaughan regards the lower beds (about 160 feet) as probably belonging to the 'Main *Syringothyris*-Zone,' and places the upper beds (about 340 feet, commencing with the thick conglomerate-bed [R 10 *h*]) in the 'Upper *Syringothyris*- and Lower *Seminula*-Zone.' This determination of their horizon brings out the interesting fact that these conglomerates are synchronous with the Pendine Conglomerate[2] of South Wales, and approach the horizon of the volcanic rocks of Weston-super-Mare.[3] It seems, therefore, probable that the Mid-Avonian disturbance and elevation, hitherto recognized only in the South-West of England and Wales, was not a local phenomenon, but was possibly part of a movement extending over a wide area.

Another remarkable conglomerate intercalated in Carboniferous Limestones occurs on the coast at Point Lane, 2½ miles north of Rush, between Loughshinny and Skerries, the contemporaneity of which with the Rush Conglomerates is discussed in the Geological Survey-memoir (*op. cit.* p. 66). This question has yet to be investigated, but it seems likely that the Point-Lane Conglomerate will prove to be on a much higher horizon.

(*c*) The Supra-Conglomerate Limestones.

The upper boundary of the Conglomerate-Group has been taken at a 5-foot conglomerate bed [R 11 *h*], with a 14-inch pebbly band on its upper surface. The succeeding beds are for the most part thin, flaggy and shaly limestones, and dark calcareous flags with, especially towards the top, occasional thicker beds of limestone, sometimes 2 feet thick. They contain several pebbly horizons, and there is a 2-foot pebbly limestone [R 12 *d*] near the top. The bed [R 12 *e*] immediately overlying this contains plant-remains, but these are in so poor a state of preservation that Mr. R. Kidston, F.R.S., who kindly examined them, can only say of them that they have 'a fern-like look.'

These limestones, etc. have the high northerly dip (60° to 65°) of the underlying group, and their outcrop terminates at the entrance to Rush Harbour. About 100 feet of beds are seen, 30 feet of which are assigned to the Upper *Syringothyris*- and Lower *Seminula*-Zone. No zonal fossils have been collected from the uppermost beds, which probably belong to the same zone.

[1] It may be remarked, in passing, that this area appears to be the most northerly spot in the British Isles in which cleavage occurs in beds of so late a period as the Carboniferous. The occurrence of cleavage so far north may be connected with the deflection of the general lines of Armorican folding in the South of Ireland by the great mass of the Wicklow Granite.

[2] 'Summary of Progress of the Geological Survey for 1904' Mem. Geol. Surv. 1905, p. 44.

[3] C. Lloyd Morgan & S. H. Reynolds, Quart. Journ. Geol. Soc. vol. lx (1904) p. 148.

(*d*) The Carlyan Limestones.

These beds are separated from those last described by the entrance to Rush Harbour; and, although a gap of only 200 feet divides the two series, there is a marked difference in the lie of the beds. On the south side of the harbour, the Upper Rush Slates, the Conglomerate-Group, and the Supra-Conglomerate Limestones have been dipping steadily at angles of 50° to 65°; while on the north side the Carlyan Beds undulate at low angles, though with a general northerly dip. From this marked change of dip, and from the fact that the numerous small faults seen on the south side of the harbour are not traceable across the harbour-entrance, and that there is some disturbance of the beds, seaward, on the north side, it seems probable that there is a strike-fault here, though of no great throw, as the two sets of rocks correspond closely in lithological character. If there is no fault, the top of the Supra-Conglomerate Limestones is about 100 feet below the horizon of the Carlyan Beds.

The latter consist of dark-grey, well-bedded limestone, and dark calcareous and argillaceous flaggy beds, which at several horizons are charged with numerous small fragments of slate and other rocks. They are quarried locally for building-purposes. They occupy a low rocky shore covered at high tide, and disappear northwards under the waters of Rush Bay at an angle of 15° to 20°, after exposing about 180 feet of beds.

Fossils are by no means abundant, and the few that have been collected are unsatisfactory for zonal purposes. They probably belong, either to the Lower, or to the Upper *Seminula*-Zone.

(*e*) The Kate Rocks.

These are low weed-covered rocks, projecting from the sands of Rush Bay, and are only accessible at low tide. They are separated from the Carlyan Rocks on the south by 300 yards of sandy beach, and by nearly the same distance from the *Cyathaxonia*-Beds on the north. They comprise a set of thickly-bedded limestones, underlain and overlain by thin, laminated, black, calcareous shales and thin limestones. They contain moreover some chert-seams, and rock-fragments have also been found in the limestone.

These beds are disposed in a rapid succession of sharp folds, which are often slightly overfolded, with the crests of the anticlines turned towards the north. Fig. 8 (p. 290) shows a section across these beds. Owing to the complicated structure, the exact thickness of the beds has not been ascertained; but probably about 90 or 100 feet are exposed, of which some 15 feet would consist of the thick beds.

At present, fossil evidence is too meagre to allow of these beds being correlated precisely. They are, in all probability, intermediate in age between the Carlyan Limestones and the *Cyathaxonia*-Beds now to be described. Their occasionally-included rock-fragments connect them with the former, and their chert-seams with the latter.

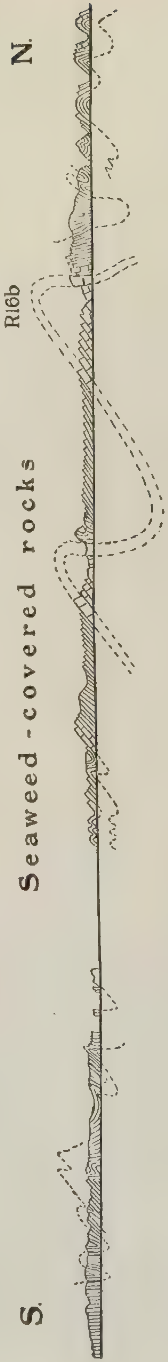


Fig. 8.—*Horizontal section through Kate Rocks, to show the folding of the limestones.* (*Length of section = about 175 yards.*)

(*f*) The *Cyathaxonia*-Beds.

These beds, which extend northward from the Bathing-Place, on the north side of Rush Bay, past Giant's Hill and Brook's End (where the section, so far as the present paper is concerned, finishes), are characterized by containing a highly-specialized coral-fauna in which species of *Cyathaxonia* are dominant, and they form a special phase of the Upper *Dibunophyllum*-Zone which Dr. Vaughan proposes to call the *Cyathaxonia*-subzone. The beds consist in part of evenly-bedded limestones with partings of shale, and in part of thin limestones, usually earthy-looking, and arranged in beds only 1 to 3 inches thick, though several such beds are often welded together to form one thick bed. Many of these thin limestones have a peculiar nodular-looking structure, which gives them an 'augen'-appearance that easily serves to distinguish them from any of the beds hitherto seen in the Rush coast-section. Interstratified with them are frequent partings and beds of shale or shaly limestone, seams of chert, and occasional thicker pure limestone-bands, not of the 'augen'-type, which, however, do not often exceed 7 or 8 inches in width.

The stratigraphical arrangement of the beds is interesting. Their strike is a little to the north of east, their dip is often high, and the beds are folded and sometimes inverted. Where they are first seen at the Bathing-Place they emerge from the shore in several small folds, of which one anticline is well exposed. In the little cliff at the Bathing Place, there is a northerly dip at 80° and over, and two small thrusts are seen, intersecting at the foot of the cliff (fig. 9, p. 291). Some quite thin limestone-bands between the two thrusts are much contorted and shattered; and some imperfect cleavage in the shales is noticeable, the cleavage dipping to the south. The beds pass up, in a few feet, into highly-contorted, decomposed shaly beds with included seams of chert. It will be shown presently that these are d e c a l c i f i e d b e d s. They form a syncline beyond which the limestones again emerge, dipping southward at an angle of 40° to 50°, while two or three adjacent beds form the long cliff-slope that bounds the south side

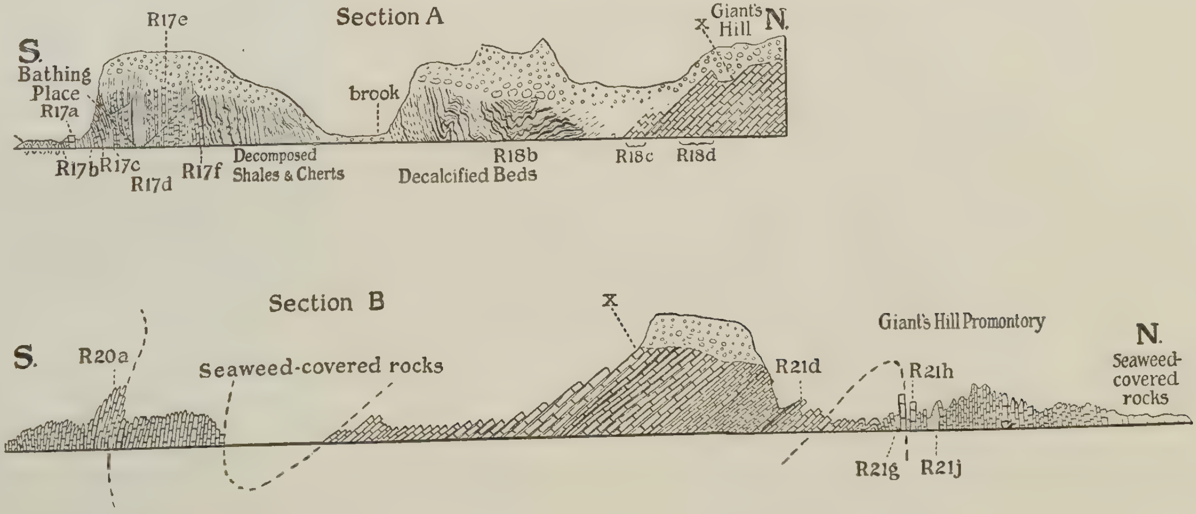
Fig. 9.—Cyathaxonia-*Beds at the Bathing-Place, north of Rush Bay.*

[The beds are nearly vertical, and two small thrusts are seen, hading in opposite directions. The beds at the bottom of the cliff appear to have undergone a greater amount of compression than the beds above, and thus have produced the effect of thrusts in the upper beds.]

Fig. 10.—Cyathaxonia-*Limestones on the coast at Giant's Hill, looking eastward.*

[The thinly-bedded limestones are nearly vertical. They are crossed by close parallel joints dipping southward, which appear to be of the nature of rough, imperfect cleavage-planes.]

Fig. 11.—*Parallel sections through the* Cyathaxonia-*Beds, between the Bathing-Place, north of Rush, and Brook's End, on the horizontal scale of 120 feet to the inch.*



[Section B is seaward of A, and the bed marked x in the latter corresponds with that which is similarly marked in the former.]

of Giant's Hill. Following these beds to the seaward face of Giant's Hill, another good section in the *Cyathaxonia*-Beds is exposed. The rocks are here arranged in an asymmetrical anticline, the northern slope of which as far as Brook's End is vertical, while the southern has a dip of only 35° to 45° ; and in the core of the arch are several minor folds with a tendency to be overfolded or overthrust towards the north. The 'augen'-looking character of the thin limestones is well marked in many of the beds here.

Returning now to the Bathing-Place, we can walk at low tide to the rocks seaward of it, and make a traverse to the north parallel with the section in the cliff. The beds are somewhat overturned at the commencement, but the structure is practically a simple syncline of which the central beds are unexposed through the drifting-in of sand. We begin with a horizon that can be followed to the cliff, and we end with a horizon that can be traced into the cliff; but the intermediate beds of the syncline are very different in the two parallel sections. Seaward, the beds are of the ordinary character previously described, that is to say they are for the most part limestones; whereas all the limestones have disappeared from the beds of indubitably the same horizon in the cliff-section, where all that is left in lieu of the original rocks is a contorted, weathered, and ironstained mass of shale and chert, representing the insoluble residue of the beds after the removal of the calcareous matter. These decalcified beds have a thickness of apparently about 100 feet, which of course represents a much greater thickness of the original rocks. On each side of the syncline enclosing the decalcified material, the limestones are for some little distance rather rotten and partly decalcified, but the change to complete decalcification is more abrupt than would be expected.

The excavation of limestone by underground water, the 'piping' of chalk, and similar phenomena resulting in the local removal of limestone-beds, have of course long been known. The dwindling and disappearance of limestones by solution was discussed, from a theoretical standpoint, by Rutley in 1893[1]; and in 1903 Mr. C. T. Clough[2] described actual instances of their disappearance in High Teesdale, where the Great Limestone, 55 feet thick, is shown to have been often completely removed (especially along the outcrop) and replaced by 10 or 12 feet of soft siliceous clay ('famp'). I have myself seen further instances of limestone-solution along the Dublin coast nearer Loughshinny; and it is probable that this effect is commonly produced on a large scale in many parts of Ireland. Indeed, the origin of many of the great Irish lakes, and even of the gulfs and bays, has been held to be the result of chemical solution of Carboniferous Limestone.[3]

There are two small but interesting thrust-planes, in the black decomposed shales with cherts that form the southern margin of the decalcified beds described above. Their hade is very low, and

[1] Quart. Journ. Geol. Soc. vol. xlix (1893) p. 372.
[2] Geol. Mag. 1903, p. 259.
[3] E. Hull, 'Physical Geology & Geography of Ireland' 1878, pp. 198–209.

along them the beds have been pushed southward about 5 feet and 1 foot respectively, the upper thrust having the greater travel. These dislocations have evidently been produced since the decalcification, and they seem to be most easily explained as the effect of the movement of an ice-sheet in Glacial times.

These black shales, in which cleavage is sometimes still recognizable, are correlated by the officers of the Irish Geological Survey with the Black-Shale Series of Loughshinny, but they almost certainly belong to a lower horizon. At Loughshinny a band crowded with *Posidonomya Becheri* occurs in the limestones some 70 feet below the Loughshinny Black Shales; whereas here the uppermost limestones are in the *Cyathaxonia*-subzone below the zone of *P. Becheri*.

Dr. G. J. Hinde, F.R.S., has been good enough to examine three slices cut from the chert-bands in this locality; one from the fresh unaltered chert, one from the partly-decalcified beds, and one from the completely-decalcified area. He finds in them various foraminifera (*Endothyra*, *Nodosinella*, *Trochammina*, and *Valvulina?*), *Calcisphaera (?)*, sponge-spicules, etc. The specimen of decalcified chert is distinguished by an absence of calcareous material and foraminifera; and there are certain bodies in it which, although some of them may be cross-sections of sponge-spicules, have more the appearance of casts of simple forms of radiolaria. Dr. Hinde remarks that the chert-slices have a close resemblance to specimens in his possession from the River Hodder.

The fauna of the *Cyathaxonia*-Beds is tabulated in the faunal lists (p. 297); and from Dr. Vaughan's correlation it appears that, although these beds are represented in the South-Western Province of England and Wales, they correspond more closely, indeed precisely, with the limestones of Park Hill, Thorpe Cloud, etc. of the Midland Province of England.

(*g*) Curkeen-Hill Limestone.

Curkeen Hill does not lie on the coast, but is a locality inland, near an old quarry on the road from Rush to Skerries, near Loughshinny. A list of the fauna of its limestone-beds and their correlation are introduced here, because the beds occupy a gap in the Rush sequence; and there was a unique opportunity during the present year (1905) of collecting fossils from them, owing to the lowering of the road at the top of the hill in order to reduce the gradient. The limestone is a rock of a lighter grey colour than the limestones seen at Rush. The Geological Survey-map indicates that the horizon of this limestone lies below that of all the rocks of the Rush section, although Jukes expressed in the Survey-memoir (*op. cit.* p. 66) his reluctance to accept this view on stratigraphical grounds. That his objection was well founded is now proved by the result of the zonal examination of the fossils, which shows that the Curkeen-Hill Limestone is of Upper *Dibunophyllum*-age (D_2), though probably older than the *Cyathaxonia*-Beds of Rush.

IV. Summary of Conclusions. [C. A. M.]

The following is a summary of the most important points referred to in this paper.

(1) The Carboniferous rocks at Rush consist of about 2500 feet of slates, conglomerates, and limestones, which range from the Upper *Zaphrentis*-Zone to the Upper *Dibunophyllum*-Zone (*Cyathaxonia*-subzone).

(2) The Conglomerates belong to the *Syringothyris*-Zone, and indicate that the Mid-Avonian elevation and disturbance recently noted at Pendine and Weston-super-Mare extended into Ireland.

(3) There is a general upward succession of the beds from south to north, and the rocks have all been subject to severe earth-pressure acting from the south. Many of the beds are well cleaved, and the limestones have been thrown into many acute folds and are sometimes slightly overfolded.

(4) Among the *Cyathaxonia*-Beds local decalcification has caused the complete disappearance of a considerable thickness of limestones.

(5) The limestone of Curkeen Hill is of Upper *Dibunophyllum*-age, but probably of a lower horizon than the *Cyathaxonia*-Beds of Rush.

In conclusion, I wish to express my very great indebtedness to Dr. Vaughan for his ungrudging help in undertaking the examination and description of the fossils from these beds, and for contributing the following account of the correlation of the rocks at Rush: also to Dr. G. J. Hinde, Dr. Wheelton Hind, Dr. A. H. Foord, Dr. F. A. Bather, and Mr. R. Kidston, F.R.S., for assistance in determining certain of the fossils; and finally to Mr. C. Murray, B.A., of Dublin, for help in collecting the fossils.

V. Faunal Lists.[1] [A. V.]

The Slates (*Zaphrentis*-Beds).

R 1 b. *Zaphrentis* cf. *Phillipsi*.
Productus sp. (cf. *Pr. rugatus*).
Phillipsia sp.

R 4 a. *Zaphrentis* cf. *Phillipsi*.
Productus cf. *Martini* (?)
Orthothetes cf. *crenistria* (cf. mut. Z_2).
Spirifer cf. *clathratus* (?)
Spiriferid (cf. *Syringothyris* cf. *laminosa*).
Athyris sp. (cf. *A. Royssii*, mut. β).
Camarotœchia sp. (?)
Loxonema sp. (fragment).[2]
Fenestellid.
Fistuliporid.

Near R 4 a. { *Zaphrentis* cf. *Phillipsi*.
Bellerophon sp.[2]

R 5 a. *Zaphrentis* cf. *Phillipsi*.

[1] In addition to the fossils mentioned in the following lists, fragments of crinoids occur in some abundance throughout the sequence.

[2] Determined by Dr. Wheelton Hind, F.G.S.

R 6 a.	*Zaphrentis* cf. *Phillipsi.* Bisulcate *Spirifer.*	Athyrid.
R 6 b.	*Zaphrentis* cf. *Phillipsi* (abundant). *Amplexi-Caninia.* *Chonetes* cf. *crassistria.* *Spirifer* cf. *cinctus.*	*Spirifer* sp. *Syringothyris* cf. *laminosa.* *Syringothyris* sp. *Athyris* cf. *glabristria.*

Dr. F. A. Bather, F.G.S., has kindly examined the crinoids obtained from this bed, and reports as follows:—

'The crinoids appear to be *Actinocrinus* and *Platycrinus.* One of the *Actinocrinus* seems to me to be *A. polydactylus*, Miller; and the *Platycrinus* from the same bed resembles a young *Pl. expansus*, M'Coy.'

R 7 d.	*Zaphrentis* cf. *Phillipsi.*	
R 7 e.	*Amplexi-Caninia.*	*Fenestella* (abundant).
R 8 a.	*Zaphrentis* cf. *Phillipsi* and variants. *Orthothetes* cf. *crenistria* (cf. mut. C), abundant. Spiriferid.	*Athyris* cf. *glabristria* (for form compare *A. planosulcata*). Monticuliporoid (with resemblance to *Favosites parasitica*).

THE CONGLOMERATES (*MICHELINIA* cf. *MEGASTOMA*-Beds).

R 9 e.	*Syringopora* cf. *ramulosa.*	*Michelinia (?)*
R 9 g.	Densiphylloid *Zaphrentis.*	
R 10 b.	Small *Chonetes* (see Note under § VI, p. 300).	*Orthothetes.* Seminuloid Athyrid.
R 10 c.	*Productus* cf. *concinnus* (or *Pr.* cf. *Martini*; specimen crushed). *Schizophoria resupinata.*	*Spirifer* cf. *striatus.* *Spirifer* sp. *Athyris* cf. *glabristria.* *Fenestella.*
	{Limestone-inclusion in R 10 g:— Large semireticulate *Productus.* *Orthothetes.*	*Schizophoria (?)* *Athyris* cf. *expansa.* *Athyris* cf. *glabristria.*}
R 10 h.	*Syringopora* cf. *reticulata.*	
	{Limestone-inclusion in R 10 h:— *Productus* cf. *concinnus.* *Productus* cf. *rugatus.*	*Seminula*-like Athyrid. *Phillipsia.*}
R 10 j.	Carcinophylloid *Clisiophyllum.*	
R 10 k.	*Syringopora* cf. *reticulata.*	
R 10 m.	*Syringopora* cf. *reticulata.* *Michelinia* cf. *megastoma.*	{R 10 m. (Loose block.) *Clisiophyllum* aff. *curkeenense*, sp. nov.}
Below R 11 a.	*Glyphioceras* sp.[1]	

[1] Determined by Dr. A. H. Foord, F.G.S.

R 11 a. *Syringopora* cf. *reticulata*.
Michelinia cf. *megastoma*.
Densiphyllid.
Lithostrotion cyathophylloides, sp. nov.
Carcinophylloid *Clisiophyllum*.
Chonetes cf. *papilionacea*.
Spirifer cf. *striatus*.
Spiriferid (compare *Syringothyris* cf. *laminosa*).
Athyris cf. *expansa*.
Athyris cf. *glabristria* (?)

R 11 b. *Syringopora* cf. *reticulata*.
Michelinia cf. *megastoma*.
Amplexus sp.
Densiphyllum.
Cyathophyllum cf. ϕ.
Lithostrotion cyathophylloides.
Carcinophylloid *Clisiophyllum* (?)
Athyris cf. *expansa*.

R 11 d. *Lithostrotion cyathophylloides*, sp. nov.

R 11 g. *Syringopora* cf. *reticulata*.
Amplexus sp.
Lithostrotion cyathophylloides, sp. nov.
Productus cf. *concinnus*.
Chonetes cf. *papilionacea*.
Spirifer cf. *striatus*.

R 11 h. *Amplexus* sp.
Lithostrotion cyathophylloides, sp. nov.
Productus cf. *concinnus*.
Spirifer sp.
? *Syringothyris* cf. *laminosa*.

R 12 b. *Productus* cf. *fimbriatus*.
Semireticulate *Productus*. } Very fragmentary.
Athyris cf. *expansa* (?) } Very fragmentary.
Rhynchonellid.

{Precise horizon unknown, but certainly between R 9 e and R 12 b:—
Michelinia, mutation towards *Beaumontia*.}

R 12 e. Land-plants (? ferns)—fragmentary. (Examined by Mr. R. Kidston, F.R.S.)

{Limestone-bed in Rush Harbour:—
Pustulose *Productus* (cf. R 17 a).}

Carlyan Rocks.

R 14 a. *Productus* cf. *semireticulatus*.
Chonetes sp. (convex papilionacean).
Orthid.
Seminuloid Athyrid (?)

Kate Rocks.

R 16 b. *Chonetes* cf. *papilionacea* (?)
Orthothetes sp. (?)

Cyathaxonia-Zone.

R 17 a. *Amplexi-Zaphrentis* (?)
Lonsdalia (?)
Cyathaxonia rushiana, sp. nov.
Productus concinnus.
Productus scabriculo-costatus.
Productus elegans (= *Pr. punctato-fimbriatus*).
Productus fimbriato-pustulosus (cf. Davidson, 'Monogr. Brit. Foss. Brachiopoda' Palæont. Soc. pt. v, 1861, pl. xlii, figs. 1 & 2).
Productus margaritaceus.
Productus corrugatus.
Papilionaceous *Chonetes*.
Orthid (*Rhipidomella* ?).
Orthothetes cf. *radialis*.
Spirifer bisulcatus (two variants).
Spirifer triradialis.
Straparollus cf. *Dionysii*.[1]
Loxonema sp., cf. *L. sulcatum*.[1]

[1] Determined by Dr. Wheelton Hind, F.G.S.

Horizon		
R 17 b.	*Lithostrotion* cf. *cyathophylloides*, sp. nov.	*Lithostrotion Phillipsi.* Campophyllid.
{Seaward of R 17 c :—	*Lithostrotion Phillipsi* (abundant). *Productus semireticulato-longispinus.* }	
R 17 c.	*Amplexi-Zaphrentis*, subgen. nov. *Lithostrotion Phillipsi.* *Schizophoria resupinata* (abundant fragments).	Bisulcate *Spirifer* (fragment). *Seminula* sp. *Straparollus* sp.[1] Echinid-plates.
R 17 d.	*Cyathaxonia rushiana*, sp. nov. *Productus* aff. *semireticulatus.* *Chonetes* sp. (convex papilionacean).	*Schizophoria resupinata.* Fenestellid.
R 17 e.	Bisulcate *Spirifer.*	*Glyphioceras truncatum.*[2]
R 17 f.	*Cladochonus* sp. (?) *Lithostrotion* sp. (probably =R 21 j specimen). *Cyathaxonia rushiana*, sp. nov. Aulophylloid *Clisiophyllum.* *Productus concinnus.* *Productus* aff. *scabriculus.* *Productus elegans.* *Productus pustuloso-fimbriatus* (cf. *Pr. Youngianus*). *Productus margaritaceus.* *Chonetes* sp. (convex papilionacean).	*Schizophoria resupinata.* *Leptæna* cf. *distorta.* *Orthothetes* cf. *radialis.* *Spirifer bisulcatus.* *Spirifer striatus* (cf. Curkeen Limestone). *Syringothyris subconica.* *Athyris glabristria* (convergent on *Martinia glabra*). *Camarophoria* aff. *isorhyncha* (cf. Curkeen Limestone). Fenestellid. *Phillipsia* sp. (abundant).
R 20 a (in chert) :—	*Endothyra* sp. *Nodosinella* sp. *Trochammina* sp.	*Calcisphæra (?)* Spines of echinoids. Spicules of sponges.
	(Determined by Dr. G. J. Hinde, F.R.S.)	
R 21 g.	*Zaphrentis* aff. *Enniskilleni.* Clisiophylloid *Lithostrotion* (convergent on *L. cyathophylloides*). *Cyathaxonia (?)* *Productus costato-semireticulatus.* *Productus elegans.*	*Productus hemisphericus.* *Chonetes* sp. (convex papilionacean). *Schizophoria resupinata.* *Syringothyris subconica.* Spiriferid (cf. *Martinia ovalis*) fragment.
R 21 h.	Cymatiophylloid Clisiophyllid.	
R 21 d.	*Cladochonus* cf. *bacillarius.* *Cyathophyllum* sp. *Amplexi-Zaphrentis* (variant convergent on *Zaphrentis* aff. *Enniskilleni*). Caninoid Clisiophyllid. *Densiphyllum.*	*Cyathaxonia rushiana*, sp. nov. *Cyathaxonia contorta*, sp. nov. Semireticulate *Productus.* *Spirifer bisulcatus.* *Syringothyris subconica.* *Athyris* cf. *expansa.* *Athyris planosulcata (?)*
R 21 j.	*Zaphrentis* aff. *Enniskilleni.* Clisiophylloid *Lithostrotion.* *Cyathaxonia rushiana*, sp. nov.	*Productus longispinus.* *Choneti-Productus (?)* *Schizophoria resupinata.*

[1] Determined by Dr. Wheelton Hind, F.G.S.
[2] Determined by Dr. A. H. Foord, F.G.S.

R 18 d. *Cyathaxonia rushiana*, sp. nov.

R 18 c. *Amplexi-Zaphrentis*, subgen. nov.
Cyathaxonia rushiana, sp. nov.
Cyathaxonia contorta, sp. nov.
Aulophylloid *Clisiophyllum*.
Productus costato-semireticulatus.
Productus aff. *scabriculus*.
Productus margaritaceus.
Productus cf. *corrugatus* (abundant fragments).
Chonetes sp. (convex papilionacean).
Orthothetes (?)
Euomphalus crotalostomus (?) [1]
In chert { *Endothyra* sp., *Valvulina (?)*, *Calcisphæra (?)*, Sponge-spicules. } [2]

R 18 b. Athyrid (?)
(In chert) Radiolarians (?) Examined by Dr. G. J. Hinde, F.R.S.

Curkeen Limestone (correlated with the Upper *Dibunophyllum*-Zone).

Lithostrotion cyathophylloides, mut. towards *Koninckophyllum*.
Clisiophyllum curkeenense, sp. nov.
Cyathaxonia contorta, sp. nov.
Productus concinnus and variant towards *Pr. pugilis*.
Productus scabriculo-costatus.
Productus corrugatus.
Productus fimbriato-pustulosus (cf. Davidson, 'Monogr. Brit. Foss. Brachiop.' Palæont. Soc. pt. v, 1861, pl. xlii, fig. 1, and cf. *Pr. ovalis*).
Productus aculeato-fimbriatus.
Chonetes sp. (convex papilionacean).
Schizophoria resupinata (abundant) and variant towards *Rhipidomella*.
Leptæna cf. *distorta*.
Derbya (?) cf. *senilis*.
Derbya anomala.
Spirifer striatus and variants.
Martinia glabra.
Reticularia lineata (?)
Athyris glabristria (convergent on *Martinia glabra*).
Pugnax acuminatus.
Camarotœchia (?) cf. *flexistria*.
Camarophoria aff. *isorhyncha*.
Dielasma aff. *hastata*.
{ *Edmondia Lyellii*. *Conocardium inflatum*. *Bellerophon hiulcus*. *Euomphalus pentangulatus*. *Euomphalus latus*. *Platyschisma helicoides*. *Straparollus Dionysii*. *Naticopsis ampliata*. *Loxonema supremum*. } [1]
{ *Orthoceras laterale*. *Vestinautilus carinifer*. *Planetoceras globatum*. } [3]

VI. Account of the Faunal Succession and Correlation. [A. V.]

1. Fauna of the '*Zaphrentis*-Beds'; (R 1 *b* to R 8 *a*).

(i) Corals:

The one feature of importance is the abundance of a small *Zaphrentis*, resembling *Z. Phillipsi*, Edwards & Haime. With the exception of a few specimens of an ill-preserved *Caninia*-like form, *Z.* cf. *Phillipsi* is the only coral found.

(ii) Brachiopods:

The specimens are few and fragmentary, and consequently the

[1] Determined by Dr. Wheelton Hind, F.G.S.
[2] Determined by Dr. G. J. Hinde, F.R.S.
[3] Determined by Dr. A. H. Foord, F.G.S.

following determinations are subject to a considerable error of identification.

Productus cf. *Martini* ? (Sow.).
Chonetes cf. *crassistria* (M'Coy).
Orthothetes crenistria (Phil.), cf. mut. Z_2 and mut. C.
Spirifer cf. *clathratus* (?) M'Coy.
Spirifer cf. *cinctus*, Keys., de Kon.
Syringothyris cf. *laminosa* (M'Coy) (Dav. *pars*).
Athyris sp. (cf. *A. Royssii*, mut. β).
Athyris cf. *glabristria* (Phil.), and variant towards form of *A. planosulcata* (Phil.).
Camarotœchia (?)

Correlation of the '*Zaphrentis*-Beds' with the Upper *Zaphrentis*-Zone of the Avonian of the South-Western Province.—This correlation rests upon the following facts common to the two developments:—

(1) The abundance of *Zaphrentis* cf. *Phillipsi*;
(2) The absence of *Cyathophyllum*, *Lithostrotion*, and Clisiophyllids;
(3) The absence or rarity of longitudinally-ribbed *Producti*.

The abundance of *Zaphrentis* would indicate the upper division of the *Zaphrentis*-Zone.

2. Fauna of the '*Michelinia* cf. *megastoma*-Beds'; (R 9 *e* to R 11 *h*).

[The typical characters are not, however, developed until R 10 *h*.]

(i) Corals:

Syringopora cf. *ramulosa*, Goldf.
Syringopora cf. *reticulata*, Goldf.
Michelinia cf. *megastoma* (Phil.).
Michelinia (mutation towards *Beaumontia*).
Amplexus sp.
Densiphyllid.
Lithostrotion cyathophylloides, sp. nov.
Cyathophyllum cf. ϕ, Vaughan.
Carcinophylloid Clisiophyllid.
Clisiophyllum aff. *curkeenense*, sp. nov. (a less-specialized variant).

The association of *Syringopora* cf. *reticulata*, *Michelinia* cf. *megastoma*, and *Lithostrotion cyathophylloides*, in abundance, forms a striking feature of this group of beds. Of these three corals, the two first-mentioned are confined to this zone, and the last of the three is only doubtfully represented in the *Cyathaxonia*-Beds.

(ii) Brachiopods (subject to a considerable error of identification):

Productus cf. *concinnus* (Sow.).
Productus cf. *fimbriatus*.
Small *Chonetes* (possibly young papilionacean).
Large *Chonetes* (convex papilionacean).
Schizophoria resupinata (Martin).
Orthothetes.
Spirifer cf. *striatus* (Martin).
Syringothyris cf. *laminosa* ? (M'Coy).
Athyris cf. *glabristria* (Phil.).
Athyris cf. *expansa* (Phil.).
Seminuloid Athyrid.

Correlation of the '*Megastoma*-Beds' with the *Syringothyris*- and Lower *Seminula*-Zones of the Avonian of the South-Western Province.—This correlation rests upon the following facts:—

(1) *Michelinia* cf. *megastoma* and *Syringopora* cf. *reticulata* are, in the South-Western Province, confined to C and S_1, of which zones they are characteristic.
(2) *Lithostrotion* is rare at the top of C, and becomes abundant at the base of S_1.

(3) Certain structural characters of the variant of *Clisiophyllum curkeenense* are paralleled in the early Clisiophyllids from C–S_1 of the South-Western Province.
(4) *Productus* cf. *concinnus* and *Athyris* cf. *expansa* are characteristic of C-S_1 in the South-Western Province.
(5) The entrance and abundance of convex papilionaceans is highly characteristic of C in the South-Western Province.
(6) The entrance of fimbriate *Producti*, a striate *Spirifer*, and of *Schizophoria* in its typical form.[1]

3. Fauna of the '*Cyathaxonia*-Beds'; (R 17, R 21, and R 18).

(i) Corals:

Cladochonus cf. *bacillarius*, M'Coy.
Amplexi-Zaphrentis, subgen. nov.
Zaphrentis aff. *Enniskilleni*.
Cyathophyllum sp.
Densiphyllum.
Lithostrotion Phillipsi, Edwards & Haime.
Clisiophylloid *Lithostrotion*.
Caninoid Clisiophyllid.
Campophyllid.
Cymatiophylloid Clisiophyllid.
Cyathaxonia rushiana, sp. nov.
Cyathaxonia contorta, sp. nov.
Aulophylloid *Clisiophyllum*.

Cyathaxonia rushiana is highly characteristic, and occurs throughout; it is, therefore, a very valuable index.

Cladochonus is also a striking fossil, but is apparently limited to a single bed (R 21 *d*).

Amplexi-Zaphrentis and *Zaphrentis* aff. *Enniskilleni* are not uncommon, and are important from the standpoints of evolution and correlation.

The Clisiophyllids are all of a Caninoid aspect.

(ii) Brachiopods:

Productus concinnus.
Productus semireticulatus (Martin), and variants towards *Pr. costatus*, Sow., and towards *Pr. longispinus*, Sow.
Productus longispinus, Sow.
Productus scabriculo-costatus.
Productus aff. *scabriculus* (Martin).
Productus fimbriato-pustulosus and variant towards *Pr. Youngianus*, Dav.
Productus elegans, M'Coy (= *Pr. punctato-fimbriatus*).
Productus margaritaceus, Phil.
Productus corrugatus, M'Coy.
Productus hemisphericus, Sow.
Choneti-Productus (?)
Chonetes (convex papilionacean).
Schizophoria resupinata (Martin).
Leptæna cf. *distorta*, J. Sow.
Orthothetes cf. *radialis* (Phil.).
Spirifer bisulcatus, Sow. and variants.
Spirifer triradialis, Phil.
Spirifer striatus (Martin).
Syringothyris subconica (Martin).
Athyris glabristria (Phil.) convergent on *Martinia glabra*.
Athyris cf. *expansa* (Phil.).
Athyris planosulcata ? (Phil.).
Seminula sp.
Camarophoria aff. *isorhyncha* (M'Coy).

[1] I have already pointed out, in Quart. Journ. Geol. Soc. vol. lxi (1905) p. 296, that the subzonal index of Z_2 in the Avonian sequence differs rather considerably from Martin's type of *Schizophoria resupinata*. Since this leads to confusion, I have decided to reject *Schizophoria resupinata*, mut. Z_2, as a subzonal index, and to replace it by *Zaphrentis* aff. *cornucopiæ*, which therefore becomes the index of Z_2. The typical *Schizophoria resupinata* is only found in the South-Western Province at the very base of C, and no specimens have, as yet, been recorded from any other horizon.

The foregoing determinations are subject to but a small error of identification.

Correlation of the '*Cyathaxonia*-Beds' with some part of the Upper *Dibunophyllum*-Zone of the Avonian of the South-Western Province.—For the purpose of correlation the facts may be marshalled thus:—

(i) As regards the Corals:—

(1) *Cyathaxonia* and *Cladochonus* are unknown in the South-Western Province.

(2) *Amplexi-Zaphrentis* and *Zaphrentis* aff. *Enniskilleni* abound in the upper D-beds of Oystermouth (Gower).

(3) The Clisiophyllids are comparatively scarce, and do not exhibit a very advanced type of structure, the Caninoid type being predominant. They cannot be actually matched from the South-Western Province, but would appear to have reached at least as advanced an evolutionary stage as our D_1 forms.

(ii) As regards the Brachiopods:—

(1) With the exception of the fimbriate and pustulose *Producti*, the convex-papilionaceous *Chonetes*, *Schizophoria resupinata*, *Athyris glabristria*, *Athyris* cf. *expansa*, and *Camarophoria* aff. *isorhyncha*, the brachiopod-fauna of the *Cyathaxonia*-Beds may be said to be completely diagnostic of the upper D-beds of the South-Western Province. The absence of the small *Chonetes* characteristic of ϵ and the rarity of scabriculate *Producti* suggest, for the '*Cyathaxonia*-Beds,' a level at the top of D_2, below the very top of the Avonian of the South-Western Province.

(2) In the South-Western Province convex-papilionaceous *Chonetes* and *Athyris* cf. *expansa* do not transgress D_1.

Fimbriate and pustulose *Producti*, as well as *Athyris* cf. *glabristria*, have not been recorded above S_1.

Camarophoria isorhyncha (closely related, but not identical with the Rush form) is known only from the base of S_1.

Schizophoria resupinata is unknown above the base of C.

Syringothyris subconica is markedly convergent with *Cyrtina septosa*, a species which I have recently found in D_1 of Lydstep (Tenby). Regarded from an evolutionary standpoint, *S. subconica* could be derived from the gens of *S.* cf. *laminosa* by convergence with *Cyrtina septosa*; *Syringothyris* cf. *laminosa* is unknown above S_1.

The whole evidence, when proportionally weighed, seems to point with the greatest probability to the Upper *Dibunophyllum*-age of the '*Cyathaxonia*-Beds,' but the exact position which they occupy in that subzone is not as yet absolutely fixed.[1]

[1] It is very important to appreciate the fact that, during the Upper *Seminula*-period, the whole of the South-Western Province was subject to special conditions, and therefore exhibited a limited and peculiar fauna. In C and S_1 we can watch the birth and early mutation of all the gentes characteristic of Upper Avonian time; but, during the Lower *Seminula*-period, most of these groups were banished from the area, to continue their evolution elsewhere. It was not until the close of the *Dibunophyllum*-period that the normal conditions were restored, and the complete fauna returned. It is, therefore, impossible to study, from the evidence presented by the South-Western Province alone, the mutations to which each gens was subject during S_2 and D_1 time; and so too it is impossible to appreciate the exact time-value of the variations which can be observed in specimens from other areas.

Correlation of the '*Cyathaxonia*-Beds' with the uppermost beds of the Carboniferous Limestone on the south-western border of the Midland area.—During a short visit to Dr. Wheelton Hind, I had an opportunity of examining the uppermost beds of the Carboniferous Limestone, under his guidance, at a considerable number of localities lying on the margin of the Limestone-mass. The actual thickness examined cannot measure more than a few hundred feet, and exhibited two types of faunal assemblage:

(1) The rich brachiopod collecting-ground of Park Hill, Wetton, etc.

(2) The *Cyathaxonia*-Beds of Bradbourne.

(1) The Park-Hill fauna includes nearly all the brachiopods found in the '*Cyathaxonia*-Beds' of the Rush sequence, and quite a large number of forms are undoubtedly identical. Corals are scarce at Park Hill, etc., but I found the same Aulophylloid *Clisiophyllum* as that which occurs in R 17 *f* and R 18 *c*, near Wetton, and a Caninoid Clisiophyllid at Astbury, very similar to the specimen recorded from R 21 *d*.

(2) The Bradbourne Beds contain *Cyathaxonia rushiana* and *Amplexi-Zaphrentis*, even more abundantly than the Rush Beds. A further point of resemblance is the occurrence of *Cladochonus*, which Dr. Wheelton Hind pointed out to me as characterizing the Bradbourne level.

The relative position of these two types of strata in the Midlands is not, as yet, definitely settled; but, from an exposure near Kniveton, I am inclined to believe that the Bradbourne Beds immediately overlie the Park-Hill Series, and this conclusion Dr. Wheelton Hind thinks probable, from a large experience of exposures at other points of the area.

The correlation of the '*Cyathaxonia*-Beds' of Rush with the top of the Avonian in the Western Midlands is a fact beyond dispute, and so striking is the resemblance that it seems highly probable that the Rush and Western Midland beds belong to the same Province.

4. The Carlyan and Kate Rocks; (R 13 to R 16).

Fauna:—

Corals: None.

Brachiopods:

Convex-papilionaceous *Chonetes* (abundant).	*Orthothetes (?)*
Semireticulate *Productus*.	Seminuloid Athyrid.

Such an assemblage could occur at any level above Z in the South-Western Province.

5. The Curkeen Limestone.

(See special faunal list, p. 299.)

Analysis:—

(i) Corals:

Lithostrotion cyathophylloides, mutation towards *Koninckophyllum* (cf. *K.* θ of D_1, South-Western Province), and *Clisiophyllum curkeenense* both show marked development from the forms in the '*Megastoma*-Beds.'

Cyathaxonia contorta occurs also in the '*Cyathaxonia*-Beds.'

The Curkeen Limestone, therefore, should lie above the '*Megastoma*-Beds' and near the horizon of the '*Cyathaxonia*-Beds.' The stage of development suggests D_1.

(ii) Brachiopods:

The *Producti* indicate a somewhat lower level than the '*Cyathaxonia*-Beds.'

(1) Fimbriate or pustulose types are abundant.

(2) Highly-developed scabriculate types are absent, as also are the most specialized members of the semireticulate group (such as *Productus longispinus*) and the characteristic *Pr. margaritaceus*.

The *Chonetes* are convex papilionaceans.

Schizophoria resupinata is very abundant, and exhibits much individual variation of form: all its varieties could, however, be matched from Wetton, Astbury, etc.

Athyris glabristria also attains its maximum development, as it does at Kniveton in the Midland area.

Camarophoria aff. *isorhyncha* and *Leptæna* cf. *distorta*, together with the three species just cited, are common to the '*Cyathaxonia*-Beds' and the Curkeen Limestone.

The Spirifers belong to the striate group, and are apparently the descendants of the forms which make their first appearance in the '*Megastoma*-Beds' of the Rush sequence and in the *Syringothyris*-Zone of the South-Western Province.

Martinia glabra is abundant: in the South-Western Province we only know this form from D_2 (Oystermouth Limestone); it is common in the Park-Hill fauna.

Derbya anomala is identical with the Park-Hill form.

General conclusion:—The Curkeen Limestone cannot occur at any considerable distance from the '*Cyathaxonia*-Beds,' and, with great probability, lies immediately below them in some part of the Upper *Dibunophyllum*-Zone.

VII. Notes on the Genera and Species cited in the Faunal Lists. [A. V.]

If P be a generic name and x a specific name, P cf. x implies that, of all the named species of the genus P, x is that one which presents the closest resemblance to the form denoted by P cf. x.

By the use of this notation, it is further implied that there is no reason for believing that Px and P cf. x are links or appendages of the same chain of evolution (that is, Px and P cf. x are not members of the same gens).

P aff. x is any one of the links or appendages of the chain of evolution which contains the named species Px (that is, Px and P aff. x are members of the same gens).

Px cvgt. Qy implies convergence or assimilation between two contemporaneous species belonging to distinct genera.

Two cases of convergence are of common occurrence:—

(1) A general structural convergence which affects, in greater or less degree, all the genera of similar organisms living at the same time (for example, the general adoption of a Clisiophyllidan structure by the D_2 corals). This phenomenon may be termed a time-trait.

(2) A local convergence (or mimicry) by which the external form of two species belonging to distinct genera, but living in association, tends to become identical (for example, *Martinia glabra* and *Athyris glabristria* in the Curkeen Limestone).

A compound specific term, such as Pyx, indicates any form which varies from the type-species Px in the direction of the type-species Py; hence Pyx indicates an entire segment of a chain of evolution, extending from Px to Py, whereas Px and Py represent points only.

The employment of compound terms is, in many cases, more appropriate than the creation of new species when we are dealing with large divisions of time, such as are implied in zones; and especially is this the case when the whole of the segment represented by Pyx lies entirely within the zone.

BRACHIOPODS.

Semireticulate and scabriculate *Producti.*

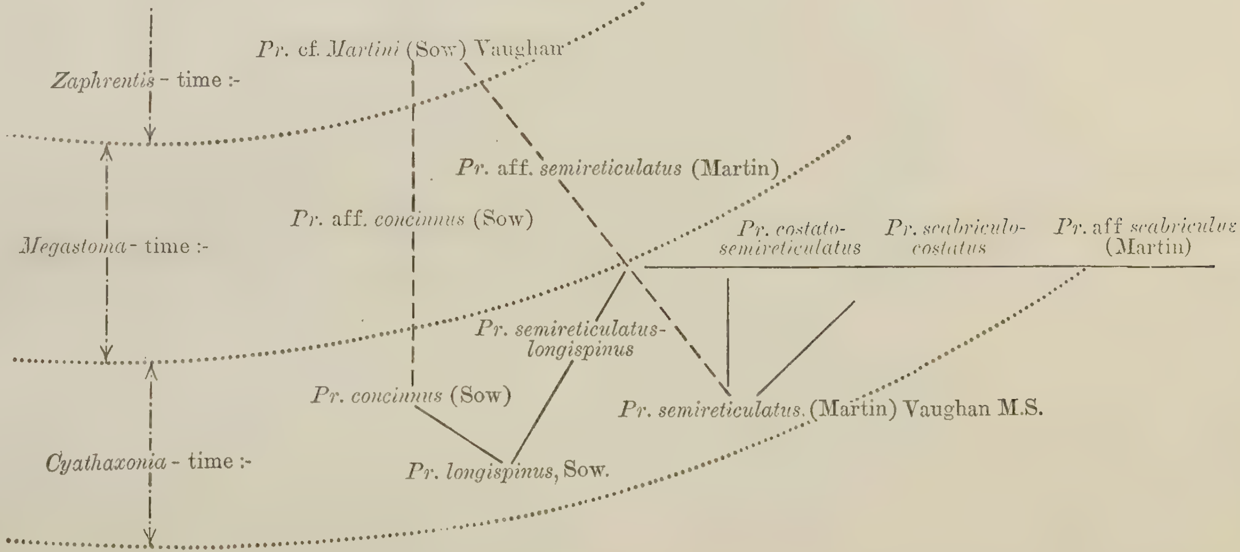
Since I am now engaged upon the detailed study of this group, it will be sufficient here merely to schematize the lines of variation which are exhibited by the group in the Rush sequence.

In the appended scheme (fig. 12, p. 306), an unmodified specific name denotes the type of the original author.

Pustulose, fimbriate, and punctate *Producti.*

The *Producti* of this group are all ornamented with numerous, regularly-arranged, short, radial, procumbent spine-bases.

Fig. 12.—*Scheme of the lines of variation exhibited by the semireticulate and scabriculate* Producti *in the Rush sequence.* *(See p. 305.)*



The three fundamental types are:—

Productus pustulosus, Phil.,[1] *Pr. fimbriatus*, J. de C. Sow.,[2] and *Pr. punctatus* (Martin).[3] Martin's type of *Pr. punctatus* and Phillips's type of *Pr. pustulosus* agree in the form of the two valves, and in the possession of numerous concentric bands, separated by sharp grooves.

They differ completely in the nature and distribution of the spine-bases. In the type of *Pr. pustulosus*, the spine-bases are broad, well-spaced pustules arranged in concentric rows, each row ornamenting one of the concentric bands. In the type of *Pr. punctatus* the spine-bases are extremely numerous, small, and closely-packed, three to four concentric rows ornamenting each concentric band. (The spines which compose the uppermost row on each band are always larger than those of the lower rows.)

The type of *Pr. fimbriatus*, J. Sow., has the following characters:—

(*a*) Pedicle-valve.—Form elongate and continuously convex, with a short hinge-line and arched beak. A small number of broad concentric ridges, separated by broad concentric depressions. Broad, well-spaced spine-bases; a single concentric row of spines ornamenting each concentric ridge.

(*b*) The brachial valve is continuously concave.

Variation (in so far only as specimens cited in this paper are concerned):—

(1) Of *Pr. pustulosus*, in a direction diverging from the fimbriate and punctate groups.—Here is included *Pr. pyxidiformis*, de Kon.,[4] the type of which exhibits irregular concentric wrinkles, feebly separated by irregular concentric ruts. Pyxidiform variants of *Pr. pustulosus* are not uncommon in the *Cyathaxonia*-Beds of the Rush sequence and in the Curkeen Limestone. They are intermediate between *Pr. pustulosus* and *Pr. pyxidiformis*, the concentric banding being irregular, but the concentric grooves distinct.

(2) Of *Pr. pustulosus*, towards *Pr. fimbriatus*.—All such variants may be included under the term *Pr. fimbriato-pustulosus*. Here is included *Pr. ovalis*, Phil.,[5] the type of which has an elongate fimbriate form (flattened over the median area of the pedicle-valve); concentric grooves are very indistinct, and the spine-bases narrow. One of the forms from the Curkeen Limestone approaches very close to *Pr. ovalis*, differing only in the more marked separation of the concentric bands.

(3) Of *Pr. fimbriatus*, towards *Pr. punctatus* (= *Pr. punctato-fimbriatus*).—Here is included *Pr. elegans*, M'Coy,[6] the type of which is, in all respects of form and banding, a pure fimbriate

[1] 'Geology of Yorkshire' vol. ii (1836) pl. vii, fig. 15.
[2] 'Min. Conch.' vol. v (1825) pl. ccccliх, fig. 1.
[3] 'Petrificata Derbiensia' 1809, pl. xxxvii, fig. 6.
[4] 'Monographie du Genre *Productus*,' Recherches sur les Animaux fossiles, pt. i (1847) pl. xvi, fig. 2.
[5] 'Geology of Yorkshire' vol. ii (1836) pl. viii, fig. 14.
[6] 'British Palæozoic Fossils' 1855, pl. iii H, fig. 4.

Productus, but the spine-ornament is exactly that of *Pr. punctatus*. This group is represented in the *Cyathaxonia*-Beds by a common form which appears to be identical with *Pr. elegans*.

In the Upper *Dibunophyllum*-Zone of the South-Western Province, a closely-similar, but larger, form is equally characteristic of the uppermost Avonian.

The specimen figured by Martin under *Pr. punctatus*,[1] as well as Phillips's figure of *Pr. fimbriatus*,[2] must be described as examples of *Pr. punctato-fimbriatus*, intermediate between *Pr. fimbriatus* and *Pr. elegans*.

A single specimen of a very peculiar fimbriate *Productus* was found by Dr. Matley just above the *Megastoma*-Beds.

The form and concentric banding are exactly those of *Pr. fimbriatus*, but the spine-bases are few, scattered, and usually erect. The relationship of such a form is very obscure, but probably it represents a link between the fimbriate and the aculeate *Producti*. The specimen is figured under the name *Productus* cf. *fimbriatus*, Pl. XXX, fig. 6.

PRODUCTUS MARGARITACEUS, Phil.

This *Productus* is highly characteristic of the *Cyathaxonia*-Beds, and it occurs at the same level, both in the South-Western Province and in the Midland area.

PRODUCTUS CORRUGATUS, M'Coy.

Specimens which appear to be identical with M'Coy's type[3] occur in the Curkeen Limestone and in the *Cyathaxonia*-Beds of the Rush sequence. The same form occurs in the Upper *Dibunophyllum*-Zone of the South-Western Province.

Chonetes.

Convex papilionaceous CHONETES.

The fragmentary nature of the specimens which have been collected from the Rush sequence forbids any more definite determination. This circumstance is much to be regretted, since, with the valuable help of Mr. T. F. Sibly, I have been carefully studying the mutation of this group, from early *Syringothyris*-time up to its acme of development in the Lower *Dibunophyllum*-Zone. The investigation depends upon the patient accumulation of specimens showing the internal characters. The material that we have already collected indicates the gradual change, from Orthothetoid convergence in Lower *Syringothyris*-time to the most pronounced Productoid convergence in Lower *Dibunophyllum*-time, as exhibited in *Producti-Chonetes* (=*Daviesiella*, Waagen) aff. *comoides*[4] of the South-Western Province.

[1] 'Petrificata Derbiensia' 1809, pl. xxxvii, figs. 7 & 8.
[2] 'Geology of Yorkshire' vol. ii (1836) pl. viii, figs. 11 & 12.
[3] 'Synopsis Carb. Limest. Foss. of Ireland' 1844 pl. xx, fig. 13.
[4] A. Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 295.

SCHIZOPHORIA RESUPINATA (Martin).

This gens occurs rarely in the *Megastoma*-Beds, but abundantly in the *Cyathaxonia*-Beds and in the Curkeen Limestone.

In the upper beds, the gens strikingly exhibits that exaggeration of characters which so frequently indicates approaching extinction. Great size and massive test, periodicity of ribbing accompanied by the development of prominent spines, numerous strongly-marked growth-lines producing conspicuous concentric ornament, deep sulcation of the brachial valve, and coarse longitudinal grooving (as in the Choneti-Productids of the same period), are among the most striking of the external characters. As regards internal characters, the muscular scars are deeply impressed and of large size; the cast exhibits strong, sharp, longitudinal ridges and a coarsely-punctate margin.

In the South-Western Province, as already noticed, no typical specimens of *Schizophoria resupinata* have yet been found in the Upper Avonian; the Lower *Syringothyris*-Zone is the only level at which typical examples are abundant. The early variant which characterizes Z_2 of that area is distinguished from the type-species by its small size and non-sulcate globose form.

On the other hand, every variation exhibited by the gens in the *Cyathaxonia*-Beds of Rush and in the Curkeen Limestone could be matched in specimens from the Wetton and Park-Hill Beds of the Midlands.

SCHIZOPHORIA[1] sp.

In the Curkeen Limestone, and associated with *Schizophoria resupinata*, occurs a small Orthid, which has a globose brachial valve and a flattened pedicle-valve. The hinge-line is short, as in a *Rhipidomella*, and the ribbing is of the type characteristic of that genus.

A closely-similar form occurs in the uppermost Avonian of Ragwen Point, near Tenby.

ORTHOTHETES (DERBYA) SENILIS (Phil.), var. (?) ANOMALA (J. Sow., *pars*).

Compare *Derbya ruginosa*, Hall.

Specimens are not uncommon in the Curkeen Limestone which have the characteristic billowy contortion; when sectioned, the pedicle-valve exhibits the strong mesial septum which is diagnostic of Waagen's genus *Derbya*.

Exactly-similar specimens are common at Park Hill (Midland area). At the base of D_1, in the South-Western Province, a

[1] This shell might equally well be termed a *Rhipidomella*. It is very doubtful whether, in the Carboniferous rocks, the distinction of *Rhipidomella* from *Schizophoria* can be considered to have generic value. There are certainly a large number of shells which can only be assigned to either genus, rather than the other, by unduly weighing one or other of the differences that are to be seen in the typical forms of *Schizophoria resupinata* and *Rhipidomella Michelini*.

transverse *Derbya* occurs somewhat abundantly; it has strong concentric ruts, but never exhibits the remarkable contortion of *Derbya anomala.*

LEPTÆNA cf. DISTORTA, J. Sow.

The dependent margin of the pedicle-valve is practically smooth, narrow, and deeply sinuated. The double-valved shell is biconvex, since the margin scarcely projects below the brachial valve.

This form occurs rarely in D_2 of the South-Western Province.

Spirifers.

Gens of SPIRIFER BISULCATUS, Sow.

Figs. 13 & 14 in pl. vi, Davidson,[1] represent very closely the commonest type found in the *Cyathaxonia*-Beds of the Rush sequence. The flank-ribs, however, increase very markedly in strength as they approach the fold or sinus, after the pattern of *Sp. grandicostatus*, M'Coy.

The same form occurs abundantly in D_2 of Gower (South-Western Province).

Gens of SPIRIFER STRIATUS (Martin).

Without undertaking the much-needed revision of the striate Spirifers, it is necessary to enumerate the most obvious of the characters exhibited by Martin's type-figure.

Broad, rectangular area, forming the widest part of the shell. Small, sharp, bicrested beak, recurved like a hook over the top line of the area. Both valves completely and sharply ribbed; the ribs are very numerous, and arranged in pairs or groups, radiating from the umbo of each valve; the ribbing on fold and sinus is on the same pattern as that of the flanks; the margin of the fold is non-truncate.

The Spirifers figured in Davidson, *op. cit.* pl. ii, and pl. iii, figs. 2, 4, 5, are probably all members of this gens; I should also include here such forms as pl. iv, fig. 4, and pl. vii, figs. 8 & 9.[2] *Spirifer planicosta*, M'Coy, should, I think, be excluded from this gens, and yet not included in the gens of *Sp. trigonalis.*

The predominant form in the Curkeen Limestone is very similar to the forms illustrated in Davidson, *op. cit.* pl. ii, fig. 17, and in pl. iii, fig. 5.

A well-marked variant, which resembles Davidson, *op. cit.* pl. vii, fig. 8, and pl. iv, fig. 4, is remarkable for its few very coarse and angular ribs, which split into groups of shorter ones as they traverse the valves. The same variant occurs in D_2 of the South-Western Province, and is there also associated with a normal member of the gens.

[1] 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) pt. v, 1858–63.

[2] The inclusion of a particular form in a certain gens must be decided by the constancy of its association (or time-sequence) with a recognized member of the gens, and not by the possession of one or more striking characters which may have been artificially set out as an exclusive test of membership.

Syringothyris subconica (Martin). (Pl. XXX, fig. 7.)

Characters of the pedicle-valve.—Form pyramidal. The area is a plane-triangle; the beak marks the apex of the area, but does not curve over it; deep angular sulcus, without ribs; the flanks are ornamented by seven or eight sharp, perfectly-radial ribs, which have a strong laminose concentric ornament.

This shell is a characteristic fossil in the *Cyathaxonia*-Beds of the Rush sequence, and is apparently not uncommon. The specimens from Rush appear to agree exactly with Martin's type-figure.[1]

A similar form (which, however, differs in the depression of the mesial fold) is figured by Davidson [2] from Wetton, and, judging from the numerous specimens in Dr. Wheelton Hind's collection, the form is common at Castleton.

In the South-Western Province only two specimens of a *Syringothyris* have yet been discovered in the top beds, and these must both be named *Syringothyris* cf. *cuspidata.*

Syringothyris cf. *laminosa* (Z_2 to S_1) differs markedly in its regularly-concave area (it has consequently a strongly *Spiriferina*-like aspect).

Martinia glabra (Martin).

This is an abundant fossil in the Curkeen Limestone. The predominant form is more transverse than Martin's type-figure (*op. supra cit.* pl. xlviii, figs. 9 & 10), and agrees more closely with the form figured by Davidson (*op. supra cit.* pt. v, pl. xi, fig. 3).

In the South-Western Province, *Martinia glabra* is only found in D_2, where it is locally very abundant (Oystermouth Beds, Gower); it is also very common in the uppermost Avonian of the Midland area.

There is, in the Curkeen Limestone, a very striking convergence between *Athyris glabristria* and *Martinia glabra*, both of which are extremely abundant there. They both possess the same contour and general convexity; the same broad, gentle, mesial swelling and shallow mesial depression; and the same broad and rounded beak-region. The widely-distinct generic characters can, however, always be made out by careful examination.

The test of the *Athyris* is completely fibrous, and has a 'matt' surface; that of the *Martinia* has a translucent lustre, due to the character of the minutely-punctured outermost layer.

When the beak is completely exposed, the *Martinia* has a triangular area and a short, straight hinge-line; the *Athyris* has no area, and the hinge-line is broadly angled.

If the test be removed from the rostral region, the *Martinia* is seen to have no dental plates; but the cast is marked by several very strong, sharp, radiating ridges, which stand up like septa. The

[1] 'Petrificata Derbiensia' 1809, pl. xlvii, figs. 6, 7, & 8.

[2] 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) Appendix, 1863, pl. lii. fig. 4.

Athyris has very strong, slightly-diverging dental plates, and the radiating ridges on the cast resemble low ribs.

ATHYRIS GLABRISTRIA, A. EXPANSA, and A. PLANOSULCATA.

I have recorded *Athyris glabristria* from various levels throughout the Rush sequence.

Athyris expansa is common in the *Megastoma*-Beds, and a single specimen is recorded from the *Cyathaxonia*-Beds.

Our knowledge of *Athyris* is, unfortunately, very incomplete, owing to the rarity with which specimens exhibit unweathered expansions. The distinction between a sheet-expansion—built up of tubular ribs webbed together, as in *Actinoconchus*, or the group of *Athyris planosulcata*, Phil., and a fringed expansion—in which the free margin of the expansion is composed of completely-detached, flattened, tubular spines, as in *Cliothyris*, or the group of *Athyris pectinifera* (Sow.), has been found to be of little assistance in the determination of specimens such as are usually met with in stratigraphical work. Specimens showing expansions are only to be found on weathered surfaces, and the continued weathering of a sheet-expansion removes the web faster than the thickened rib, thus producing a fringed margin. Unless I have been extremely unfortunate, this is the common case with specimens of *Athyris planosulcata*. The fringed Athyrids from the South-Western Province have been very carefully examined by Mr. T. F. Sibly and myself, and we have arrived at the definite conclusion that, with the probable exception of *A.* cf. *pectinifera* from D_2 of Gower, the detached spines never extend to the suture-line of the expansion, but they always spring from a more or less narrow basal lamella. Again, one part of the shell may appear to have fringed expansions, whereas the expansions in another part may be lamellæ, without any sign of fringe.

On the other hand, *Seminula* is usually separated with ease, by the absence of any trace of expansion and the terebratuliform lines of growth.

For these reasons, '*Athyris*' is here employed to cover all those Athyrids the expansions of which are either actually fringed, or may become so by weathering. It follows that 'species'-distinction becomes little more than form-denotation; the species-groups thus made are, therefore, in the nature of 'circuli,' and are, from a stratigraphical point of view, of little value.

The terms are here employed in the following sense:—

Athyris = Athyrids which exhibit fringes (either original or produced by weathering).

A. glabristria, Phil., has a gibbous, transverse form, with a broad mesial swelling and shallow depression; the beak is thick, with rounded slopes. The accentuation of the mesial swelling into a strong fold, standing out from the flanks, is, apparently, in the South-Western Province, distinctive of the Z_2 forms.

A. expansa, Phil., has a flattened, very transverse form with almost uniplanar valve-intersection and a non-prominent beak.

In the South-Western Province this form is very abundant, and characteristic of C and S_1.[1]

A. planosulcata, Phil., has a circular and uniformly-convex form, with a small pointed beak and uniplanar valve-intersection. The typical form is abundant only in the highest beds of the Avonian.

CAMAROPHORIA aff. ISORHYNCHA (M'Coy).

This fossil occurs, both in the Curkeen Limestone and in the *Cyathaxonia*-Beds of the Rush sequence. It differs from the form recorded by Mr. Sibly from S_1 of the Weston area,[2] in having more numerous ribs (which have a less outward sweep), and in the more restricted lateral lunules. It differs from M'Coy's type[3] in being much more compressed in thickness.

CAMAROTŒCHIA (?) aff. FLEXISTRIA (Phil.).

A single specimen from the Curkeen Limestone has its fold scarcely differentiated, and the fold-ribs not appreciably larger than those on the flanks.

CORALS.

SYRINGOPORA cf. RETICULATA, Goldf. (Pl. XXIX, fig. 1.)

The tubes are in parallel grouping, and, in a vertical section, at about the diameter of a tube apart. The connecting-tubes are short, and occur at points of approximation.

In a chance horizontal section, the number of actually-connected rings is relatively small, but the more closely-approximated pairs indicate the presence of a connector within a short distance of the plane of section.

In the Rush sequence this *Syringopora* is common in, and characteristic of, the *Megastoma*-Beds.

In the South-Western Province a very similar form occurs somewhat commonly in the *Syringothyris* and Lower *Seminula*-Zones, with which the *Megastoma*-Beds are here correlated. I know, however, a practically-identical *Syringopora* from the Main Limestone of Durham, a level which, judged by the associated fauna, is unquestionably of *Dibunophyllum*-age.[4]

In my account of the Bristol sequence[5] I have pointed out that the 'species' of *Syringopora* are of the nature of circuli; consequently a correlation of two levels in distant localities, based upon the similarity of the dominant Syringoporids, is partly valueless. On the other hand, in the examination of a single area, particular forms of *Syringopora* may be of great value.

Stated broadly, dimensional variation is a function of environment, whereas the degree of structural complexity is dependent on the earlier history of the gens, and is, consequently, a function of the time.

[1] T. F. Sibly, Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 556, 557.
[2] *Ibid.* p. 557.
[3] 'Synopsis Carb. Limest. Foss. of Ireland' 1844, pl. xviii, fig. 8.
[4] Specimens from Durham have been kindly submitted to me for examination by Mr. J. T. Stobbs, F.G.S.
[5] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 267.

ZAPHRENTIS cf. PHILLIPSI, Edwards & Haime.

See Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 269 & pl. xxii, figs. 2–2 *e*.

The points of resemblance with *Zaphrentis* aff. *Phillipsi*, which characterizes Z in the South-Western Province, are:—

(1) External form and dimensions.
(2) As seen in a horizontal section:—
The spacing and number of the primary septa.
The rudimentary development of secondary septa.
The strong fossula, occupied by a long fossular septum.
The antifossular group of septa, bounded below by the elongation and union of the two extreme septa, and marked off from the fossular group by rudimentary lateral septal breaks.

The differences, are, however, strongly marked in the following characters of the Rush *Zaphrentis*:—

The septa composing the fossular groups are directed towards the centre, and not towards the walls of the fossula; the fossula is, consequently, bounded by a single septum on each side, and is narrowly rectangular in section.
The middle of a horizontal section exhibits concurrent septa, whereas, in the *Zaphrentis* of the South-Western Province, the inner ends of the septa are merged into a dense central disc, formed by the intersection of the plane of section with one of the tabulæ.

In these differences *Zaphrentis* cf. *Phillipsi* makes an approach towards *Z.* aff. *Enniskilleni* (see p. 315), but the latter exhibits the following distinctive characters:—

(1) The tendency of the antifossular septa to fall short of the centre;
(2) The fossula lies on the concave side of the coral, whereas, in *Z.* cf. *Phillipsi*, it is, apparently, always on the convex side;
(3) The absence of a long fossular septum; and
(4) The larger dimensions.

Fig. 13.—Zaphrentis *cf.* Phillipsi, *E. & H.*, *variant towards* Z. Bowerbanki, *E.&H.*, *showing the cross-section of the axial tube. From the* Zaphrentis - *Beds of Rush.*

Two rather striking peculiarities are commonly exhibited by variants of the Rush *Zaphrentis*:—

(1) A marked development of an antifossular break, which strongly resembles the fossular break.

This character is also exhibited, though less commonly, in the *Zaphrentis* of the South-Western Province (see pl. xxii, fig. 2 *c*, *op. supra cit.*).

(2) The frequent development of an axial tube caused by the wrapping-round of the septa.

In this character there is a distinct approximation towards *Z. Bowerbanki*, Edwards & Haime, but the Rush coral is always separated by its short conical form, and by the fact that the antifossular septum does not extend into the axial tube (see fig. 13).

More information is required as to the tabulæ of the Rush *Zaphrentis*, but this can only be obtained from good vertical sections.

Range.—The *Zaphrentis*-Beds only.

Zaphrentis aff. Enniskilleni, Edwards & Haime. (Pl. XXIX, fig. 2.)

This gens includes a large number of closely-related forms which occur abundantly in the uppermost Avonian, and are diagnostic of that level.

The form is always conical and usually cornute.

The septa are strongly separated into three groups, namely, two fossular groups and one antifossular group. The fossula is extremely-well developed, and the lateral breaks are usually very strong. The tabulæ are, however, Amplexoid; the fossular septum is either absent or very short.

To this gens may be referred the corals figured by James Thomson in his pl. vi, figs. 4 & 10.[1]

Specimens are common in the *Cyathaxonia*-Beds of Rush, and at the same level at Bradbourne (Derbyshire). In the South-Western Province the gens is equally prolific in the uppermost Avonian of Gower.[2]

Amplexi-Zaphrentis (subgenus nov.). (Pl. XXIX, fig. 7.)

Thomson, Proc. Phil. Soc. Glasgow, vol. xiv (1882–83) pl. vi. figs. 3, 9, & 13.

Form.—Conical, straight or curved.

Septal characters exhibited in a horizontal section.—The septal grouping is remarkably different at different stages of growth in the same individual:

(1) In the early stage. The septa are few in number and so closely approximated that the interspaces are extremely narrow; they are attached to the thick wall by very broad bases, and taper gradually towards the centre without bending.

The symmetry is strongly bilateral, the axis of symmetry being defined by two collinear septa which are respectively the longest and shortest of the septal series.

(2) In the intermediate stage. Many of the septa become shorter; broad tabulæ are developed; and a fossula is marked out, both by a break in the septal series, and by a shallow depression of each tabula.

In this stage two lateral and opposite septa often stretch across the corallum to meet in the centre, and separate an antifossular group of short septa from the two lateral groups on either side of the fossula. At the same time, broad lateral gaps may be developed in the septal sequence. Fig. 7 (Pl. XXIX) illustrates a variant of this description, and a comparison of the figure with fig. 2 of the same plate will show how deceptive is the convergence between this stage of *Amplexi-Zaphrentis* and the group of *Zaphrentis* aff. *Enniskilleni*, notwithstanding the fact that the early and late stages of the two groups are entirely distinct. Thomson's fig. 3, above cited, appears to be a typical example of the intermediate stage of an *Amplexi-Zaphrentis*.

(3) In the late stage. The septa all become short; flat tabulæ extend completely across the corallum, but bend down near the wall. The fossula is a

[1] 'Corals of the Carboniferous System of Scotland' Proc. Phil. Soc. Glasgow, vol. xiv (1882–83).

[2] I am at present engaged on the detailed study of these specimens, and consequently defer a more exhaustive account of the relationships of the gens.

broad shallow depression in each tabula, and is occupied by one or more short septa. Figs. 9 & 13 of Thomson, above cited, illustrate this stage.

(4) In the latest stage the outer wall partly splits, and the interspace is broadly vesicular, thus simulating a *Caninia*.

This subgenus occurs in the *Cyathaxonia*-Beds of Rush and Bradbourne; it is also found in the uppermost beds of the Avonian throughout the South-Western Province, where it is especially common in D_2 and ϵ of Oystermouth (Gower).[1]

CYATHAXONIA RUSHIANA, sp. nov. (Pl. XXIX, figs. 3, 3 *a*, & 3 *b*.)

Compare *Cyathaxonia cornu*, Mich., M'Coy ('Brit. Palæoz. Foss.' 1855, p. 109).

Form.—An elongated narrow cylinder, starting as a short curved cone.

Calyx.—Boundary a circle, with its plane perpendicular to the axis; rim sharp; from the middle of the calyx-floor projects a strong 'columella.' This 'columella' is a complex structure, consisting essentially of a thick tube surrounding a stout columellarian lath, the interspace being completely filled up.

Horizontal section.—Central area: oval and completely filled up, but the enclosing ring well-marked.

Septa: regular, radial, and well-spaced; 20 to 25 in number; all the septa are bilamellar, and, in the greater number, the lamellæ are separated near the periphery. The septal break is marked out by a unique thin septum, collinear with the columellarian lath.

This species is common at Rush in the *Cyathaxonia*-Beds, to which zone it is confined. The same species is abundant at Bradbourne (Derbyshire) at the same level.

So closely does M'Coy's description of *Cyathaxonia cornu* apply to the forms here included, that a new specific name might seem unwarranted; the reasons for its creation are as follows:—

(1) The axis of *C. cornu* is merely described by M'Coy as 'solid,' whereas the axis of all specimens of *C. rushiana* exhibits a very characteristic tubular structure.

(2) *Cyathaxonia cornu* is insufficiently defined by Michelin, and the identity of *C. cornu*, as a species, rests upon its interpretation by Edwards & Haime.[2] The description given by these authors does not suggest the characters of *C. rushiana*.

---

[1] I have carefully examined the specimens from Gower, and have had several sections cut from the same individuals, in order to observe the stages of growth; the above description of *Amplexi-Zaphrentis* is founded on the results of this examination. More study is, however, required to determine the relationship of the Upper Avonian forms with certain corals which occur in γ and C_1 of the South-Western Province and also with the '*Amplexi-Caninia*' which occurs in the *Zaphrentis*-Beds of Rush. The full description and illustration of this subgenus is consequently deferred.

[2] 'Monogr. des Polypiers Foss. des Terr. Paléoz.' 1851, p. 320 (Archives Mus. Hist. Nat. vol. v).

(3) The type-specimen figured by Michelin[1] was derived from Tournai, and therefore, presumably, from the Lower Avonian; all our specimens came from the top of the Upper Avonian.[2]

CYATHAXONIA CONTORTA, sp. nov. (Pl. XXIX, figs. 4 & 4 *a*.)

Form: short, conical, cornute.

Epitheca: strongly annulated and indistinctly costate.

Calyx: boundary a circle, perpendicular to the axis; rim sharp; inner slope radiated by a single series of equal, well-spaced septa; from the middle of the floor projects the very prominent, tall, laterally-compressed columella, the sides of which are roughened by vertical ridges.

Horizontal section.—Septa 30 to 40 in number, thick, simple, and bent. A distinct septal break is occupied by a short septum. All the septa are attached to the thick wall by an enlarged base.

The central area has an irregular, heart-shaped boundary, which is strongly thickened; within this bounding ring is the cross-section of the columella, finely serrated on its sides, the interspace being occupied by vesicles.

The interseptal spaces show a very few tabular intersections, the tabulæ having a very high slope.

Occurrence.—In the *Cyathaxonia*-Beds, where it is less abundant than the associated *C. rushiana*.

Relationship.—*C. contorta* resembles *C. rushiana* only in its central area. The septa differ markedly: in *C. contorta* they are single, bent, and numerous; in *C. rushiana* they are few in number, paired, and straight. In *C. contorta* the interseptal spaces are traversed by sparse tabulæ; in *C. rushiana* there are apparently neither tabulæ nor vesicles. The form of *C. contorta* is a

[1] 'Icon. Zooph.' 1840–47, p. 258 & pl. lix, fig. 9.

[2] M'Coy, however, states (*loc. cit.*) that he compared *Cyathaxonia cornu*, M'Coy, with specimens from Tournai, and found the 'coincidence exact.'

Mr. A. L. Leach, who has collected very carefully from the Carboniferous Limestone of the Tenby district, has very kindly allowed me to examine two specimens of a *Cyathaxonia* which he has discovered in the Lower Avonian of that locality.

In both specimens the calyx is well exposed, and exhibits a prominent columella which is apparently solid.

The septa, as seen in the calyx, are simple and alternate. The larger septa extend to the columella, the shorter project a very short distance from the wall. (It is unfortunate that the friable nature of the specimens forbids any attempt to obtain a horizontal section.) In the smaller specimen there are sixteen primary septa; one of these is shorter than the rest, and occupies a non-prominent septal break.

The form is cornute and conical, with a tendency to become cylindrical in the adult stage. The larger specimen has a length of 12 millimetres and a calyx-diameter of 4 mm.

Mr. Leach informs me that the larger specimen is from West Angle and probably from the top of K_2, and that the smaller specimen is from Freshwater West and from Z.

These specimens appear to agree in essential characters with the description of *Cyathaxonia cornu* given by Edwards & Haime, and may be tentatively assigned to that species.

uniformly-expanding cone, whereas *C. rushiana* is, for the greater part of its length, purely cylindrical.

In many respects *C. contorta* approaches near to *C. costata*, M'Coy.[1] Compare Pl. XXIX, fig. 5. Both have the same form and dimensions; in both the septa are simple and thickened; both have sparse tabular intersections in the interseptal spaces; and both have a dense central area.

The differences are, however, well marked:—*C. contorta* has numerous septa (thirty to forty), and the septa are strongly bent. *C. costata* has a small number (twenty-five or less) of straight septa. In *C. costata* the epitheca is strongly costated; in *C. contorta* the costation is suppressed. *C. costata* is said to have a solid central axis; whereas, in *C. contorta*, the central area is made up of a dense ring surrounding a columellarian lath, the interspace being vesicular.

Evolution of *Cyathaxonia*.—It seems possible that the *Cyathaxoniæ* of the upper beds are derived by direct descent from the tubular variant of *Zaphrentis* cf. *Phillipsi*, by the strengthening of the septa and of the central tube.

The purely-radial type of septation, as exhibited in *Cyathaxonia rushiana*, probably indicates parallel development with *Densiphyllum* (see below) due to convergence. The central columellarian lath is also, most probably, an instance of convergence with the Lithostrotions and Clisiophyllids of the Upper Avonian.

The absence of *Cyathaxonia* from the South-Western Province may be accounted for, by the fact that *Zaphrentis* aff. *Phillipsi* does not there show any tendency towards the production of a central tube.

DENSIPHYLLUM. (Pl. XXIX, fig. 6.)

This genus is here employed in the sense in which it is interpreted by Thomson.[2] The corals included here have the cornute form which is common to both *Zaphrentis* and *Cyathaxonia*; they have the septation of *Cyathaxonia*, but differ from this genus in the absence of a well-defined central axis.

The most typical group of the genus is not represented in the Rush sequence, and the majority of the specimens collected from these beds may be more correctly termed Densiphylloid *Zaphrentes*. Densiphylloid *Zaphrentes* are occasionally met with throughout the sequence; but the earlier examples are mere variants of *Zaphrentis* cf. *Phillipsi*: whereas the upper forms are more specialized, and show relationship with *Cyathaxonia costata*, M'Coy. The figured specimen from the *Cyathaxonia*-Beds is of this type, and is a *Zaphrentis* in which the septation is purely radial and almost devoid of septal break; the wall is extremely thick, and the septa reach almost to the centre, where their thickened ends are webbed together by small tabular expansions. An example of a different type is noticed under *Amplexi-Zaphrentis*.

[1] 'Brit. Palæoz. Foss.' 1855, p. 109, & pl. iii C, fig. 2.
[2] Proc. Phil. Soc. Glasgow, vol. xiv (1882–83) p. 445.

Lithostrotion cyathophylloides, sp. nov. (Pl. XXX, figs. 1, 1 *a*, & 1 *b*.)

Description.—Habit of growth: simple? (I have seen no definite evidence of compound forms.)

Form: cylindrical or elongate-conical.

Epitheca: thin, annulated by fine striæ and broad, low swellings.

Calyx: calyx-wall thick, and built up of numerous septa and of closely-packed interseptal vesicles; the inner slope of the wall is steep. Calyx-floor radiated by the primary septa, which extend to the centre. The central portion of the floor rises into a ridged tent, up the slopes of which run the primary septa; the ridge is crested by the thickened columellarian plate.

Horizontal section.—Peripheral area: often wanting, and never continuous round the whole circumference; where developed, it is thin and purely vesicular.

External area: broad, and closely radiated by the two cycles of septa; there are eight to ten rows of vesicles in the interseptal spaces.

Medial area: narrow, and almost clear of interseptal vesicles. The primary septa cross the area, but the secondary septa only project for a short distance into its outer margin.

Central area: completely radiated by the primary septa, which are crossed by about seven tabular intersections; the outer intersections are more closely approximated, so as to produce a conspicuous ring of denser structure. The columella is an elongated central plate.

Septa: not appreciably thickened in any part of their length. The primary septa are distinctly flexuous in the central area.

Measurements.—The central type has a diameter of about 21 millimetres, and has about forty-four primary septa; the relative proportions of the areas are best appreciated from the figure of a horizontal section (Pl. XXX, fig. 1 *a*).

Range and variation.—(1) The central type is abundant in the *Megastoma*-Beds; the specimens named *Lithostrotion* cf. *cyathophylloides* from the *Cyathaxonia*-Beds have only been examined in rough fracture.

(2) A mutation occurs somewhat sparingly in the Curkeen Limestone. This mutation is easily distinguished by its more numerous septa (about fifty) and by the less open character of the medial area, due to the greater elongation of the secondary septa (see Pl. XXX, fig. 1 *b*).

Comparisons.—(1) With other Lithostrotions: *L. affine* agrees in the considerable development of vesicles in the external area; but differs in the shortness of the septa, which do not extend to the centre. The large Nematophylla (that is, the basaltiform Lithostrotions) agree in:

(*a*) The extension of the septa to the centre; and (*b*) the conical tabulæ of the central area and the columella.

They differ, however, in the smaller number of their septa, as well as in their manner of growth.

(2) With the *Cyathophylla*: *Cyathophyllum* ϕ presents a very marked convergence on *Lithostrotion cyathophylloides*, for

(*a*) The characters of septa and vesicles are identical; and (*b*) both forms have well-developed tabulæ.

The only independent property in which *L. cyathophylloides* differs from *Cyathophyllum* ϕ is the elevation of the central portion of the tabulæ into tent-like projections, with the necessary accompaniment of a columellar plate.

(3) With the Clisiophyllids: The tent-like tabulæ of the central area, radiated by prolongations of the primary septa, most probably represent the ancestral character of the Clisiophyllids; but a true Clisiophyllid always exhibits a differentiation of the radii of the central area into distinct 'lamellæ.' Among the Clisiophyllids, *Lithostrotion cyathophylloides* most nearly resembles *Koninckophyllum*. Such a form as *Koninckophyllum* θ agrees with *L. cyathophylloides* in:

(*a*) The broad external area, completely radiated by the two cycles of nearly-uniform septa and closely packed with fine vesicles; (*b*) the elongation of the primary septa towards the centre; and (*c*) the columellarian plate.

Koninckophyllum θ differs, however, in its higher structural development, as shown by:

(*a*) The more numerous vesicles; and (*b*) the distinct, if rudimentary, development of lamellæ in the central area.

CLISIOPHYLLUM CURKEENENSE, sp. nov. (Pl. XXX, figs. 2 & 2 *a*.)

Description.—Simple corals, of elongate-conical form.

Horizontal section.—External area: narrow, radiated by both cycles of septa; the interseptal spaces occupied by a row of four vesicles (or fewer). Inner and outer walls strongly thickened.

Medial area: radiated by equal, thick, thorn-like primary septa, about 40 in number. The primary septa increase uniformly in thickness outward towards the inner wall. The secondary septa are also thorn-like, and project inward into the medial area for a very short distance from the inner wall. One primary septum is somewhat shorter than the rest, and forms a very inconspicuous septal break.

Central area: composed of numerous, concentric, tabular intersections, which are but slightly broken by the few and feebly-developed lamellæ. The outer margin of this area is very open in structure. The columellarian plate is strongly thickened and lentiform; it is confined to the middle of the area, but, owing to the strong development of one of the lamellæ, it is often apparently prolonged towards the septal break.

Range and variation.—*Clisiophyllum curkeenense* makes its first appearance in the *Megastoma*-Beds.

(1) This early form has a small central area, distinguished in a horizontal section by the strength and close approximation of the concentric intersections. The external area is very narrow, and for the most part merely radiated by septal teeth, which project into it from the thick outer wall.

(2) The central type occurs somewhat commonly in the Curkeen Limestone. In this form the external area is finely vesicular, and the septal prolongations which radiate the area are thin and inconspicuous. (Hence the differentiation of the external area is a conspicuous feature.) The central area is broader, and its structure looser, than in the earlier form.

Examples from the South-Western Province.—The earlier form occurs in the upper part of the *Syringothyris*-Zone; and I have a specimen from the Upper *Dibunophyllum*-Zone of Pendine that is almost identical with the Curkeen type.

EXPLANATION OF PLATES XXIX & XXX.

Plate XXIX.

Avonian Corals from Rush.

Fig. 1. *Syringopora* cf. *reticulata*, Goldf. (p. 313). Horizontal section and calices; natural size. R 10 k. *Megastoma*-Beds; coast-section, Rush.

2. *Zaphrentis* aff. *Enniskilleni*, Edwards & Haime (p. 315). Horizontal section; × 1·2. R 21 g. *Cyathaxonia*-Beds; coast-section, Rush.

Figs. 3, 3 *a*, & 3 *b*. *Cyathaxonia rushiana*, sp. nov. (p. 316).

Fig. 3. View of calyx and exterior (taken at 45° to the plane of symmetry); natural size. *Cyathaxonia*-Beds; Bradbourne (Derbyshire).[1]

3 *a*. Horizontal section of the same specimen; × 1¾.

3 *b*. Weathered fragment (showing the axial tube and enclosed columella); natural size. R 21 d. *Cyathaxonia*-Beds; coast-section, Rush.

Figs. 4 & 4 *a*. *Cyathaxonia contorta*, sp. nov. (p. 317).

Fig. 4. View of exterior (the calyx-wall is removed to show the columella); natural size. R 18 c. *Cyathaxonia*-Beds; coast-section, Rush.

4 *a*. Horizontal section of a larger specimen; × 1·2. R 21 d. *Cyathaxonia*-Beds; coast-section, Rush.

Fig. 5. '*Cyathaxonia*' aff. *costata*, M'Coy (p. 318). Horizontal section; × 1·5. *Cyathaxonia*-Beds; Bradbourne (Derbyshire).

6. *Densiphyllum* (Zaphrentoid subdivision) (p. 318). Horizontal section; × 1¾. R 21 d. *Cyathaxonia*-Beds; coast-section, Rush.

7. *Amplexi-Zaphrentis*, subgen. nov., variant convergent on *Zaphrentis* aff. *Enniskilleni* (p. 315). Horizontal section; × 1·2. R 21 d. *Cyathaxonia*-Beds; coast-section, Rush.

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[1] I had intended to illustrate this species solely from the Irish material; but, although specimens are abundant in the Rush section, the matrix does not lend itself readily to the cutting of good slices. The photograph of one such slice was quite unsatisfactory; and, though five more slices were cut, none of them was sufficiently good to serve as a representation of this very important zonal form. I consequently had to fall back upon the more tractable material from Bradbourne (Derbyshire). I can see no essential differences between the Bradbourne and the Rush forms.

PLATE XXX.

Avonian Corals and Brachiopods from Rush.

Figs. 1, 1 *a*, & 1 *b*. *Lithostrotion cyathophylloides*, sp. nov. (p. 319).
Fig. 1. Calicular view (showing the columella cresting a conical tabula); natural size. R 11 g. *Megastoma*-Beds; coast-section, Rush.
1 *a*. Horizontal section; slightly enlarged. R 11 a. *Megastoma*-Beds; coast-section, Rush.
1 *b*. A mutation. Horizontal section; × 1·2. Curkeen Limestone, Curkeen.

Figs. 2 & 2 *a*. *Clisiophyllum curkeenense*, sp. nov. (p. 320).
Fig. 2. Horizontal section; slightly enlarged. Curkeen Limestone; Curkeen.
2 *a*. A less-specialized variant. Horizontal section; slightly enlarged. R 11 a. *Megastoma*-Beds; coast-section, Rush.

Figs. 3, 4, & 5. Complex structural types cited in the faunal lists.
Fig. 3. Carcinophylloid *Clisiophyllum*. Horizontal section; slightly enlarged. R 10 j. *Megastoma*-Beds; coast-section, Rush.
4. Campophyllid. Horizontal section; slightly enlarged. R 17 b. *Cyathaxonia*-Beds; coast-section, Rush.
5. Cymatiophylloid Clisiophyllid. Horizontal section; slightly enlarged. R 21 h. *Cyathaxonia*-Beds; coast-section, Rush.

Fig. 6. *Productus* cf. *fimbriatus* (p. 308). Pedicle-valve; slightly enlarged. R 12 b. Top of *Megastoma*-Beds; coast-section, Rush.
7. *Syringothyris subconica* (Martin) (p. 311). Pedicle-valve; natural size. R 21 d. *Cyathaxonia*-Beds; coast-section, Rush.

DISCUSSION.

The PRESIDENT congratulated the Authors on this very interesting paper, and felt that it must be a source of gratification to Dr. Vaughan to see that his classification, founded upon study of the Bristol area, was being applied to an ever-widening tract. He was interested in many of the structures which had been projected on the lantern-screen: they certainly reminded him of structures seen among the knoll-like masses of limestone described by Mr. Tiddeman in the West Riding of Yorkshire.

Mr. G. W. LAMPLUGH, from personal experience of the section, heartily congratulated the Authors on their success in interpreting its intricacies. The classification of the Carboniferous Limestone in Ireland, based hitherto on lithological characters, stood in much need of revision under modern methods of research. The coast between Rush and Skerries offered the most favourable section known to the speaker for the first stages of this work; and he was delighted when Dr. Matley undertook the task, being assured that valuable results might be expected. The present paper justified this expectation, and promised well for the further results to be obtained from the remaining portion of the section, between Loughshinny and Skerries. He particularly hoped that this further work would demonstrate beyond doubt whether the Rush Conglomerates and the Skerries Conglomerates do actually represent two distinct and widely-separated horizons, as Jukes believed, since on this matter the interpretation of the structure of this Carboniferous basin largely hinged.

Mr. W. A. E. USSHER thought that the photographs exhibited

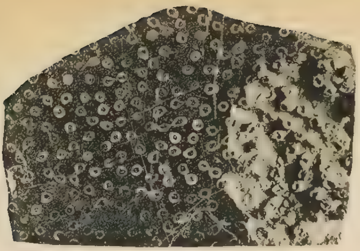

Fig. 1

Fig. 2

Fig. 3

Fig. 3b

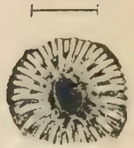

Fig. 3a

Fig. 5

Fig. 4

Fig. 4a

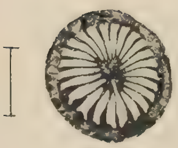

Fig. 6

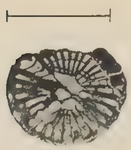

Fig. 7

AVONIAN CORALS from Rush (County Dublin).

J. W. Tutcher, Photo. *Bemrose, Collo.*

FIG. 1a

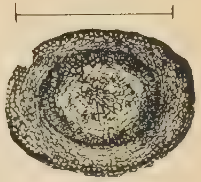

FIG. 1b

FIG. 1

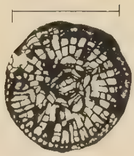

FIG. 2a

FIG. 2

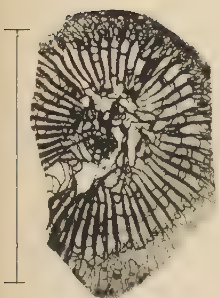

FIG. 5

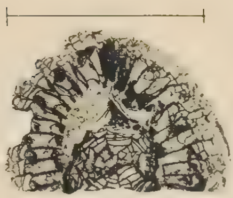

FIG. 3

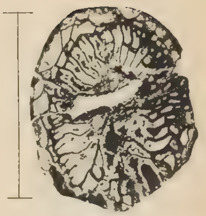

FIG. 4

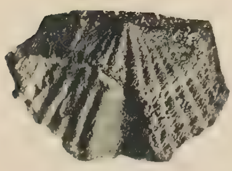

FIG. 7

FIG. 6

AVONIAN CORALS AND BRACHIOPODS FROM RUSH (COUNTY DUBLIN).

J. W. Tutcher, Photo. *Bemrose, Collo.*

furnished an excellent object-lesson in rock-structure, and suggested such constant repetition, that he wished to ask whether the thickness assigned to the Rush Slates might not be exaggerated. The nodular limestone strongly suggested the folding of thin bands on their axes of contortion and in-sheared with the slates. He also commented on the apparent passage of limestone in beach-reefs into slates with chert and decomposed limestone-bands in the cliff, as suggestive of the sudden thickening of limestone-bands, and this tended to deprive lithological character of some of its value as an indicator of horizon in the Carboniferous System.

Dr. F. A. Bather enquired whether the term Avonian was intended to apply merely to the Carboniferous Limestone Series of the South-West of England, or whether it was intended to denote a division of Carboniferous time. If the latter, then how was the term to be justified when there already existed a 'Bernician Epoch,' including the Viséan and Tournaisian Ages? [1]

Dr. Vaughan thanked the President for his kind remarks. In reply to Dr. Bather, he pointed out that the term Avonian had already been defined in his earlier paper dealing with the Bristol sequence.[2] As a stratigraphical term, Avonian denotes the whole series of deposits, of which the zones from *Cleistopora* to *Dibunophyllum* are the constituent parts. As a necessary consequence of its faunal basis the term is also an index of relative time, and Avonian time at any place denotes the time during which all the zones from *Cleistopora* to *Dibunophyllum* were being deposited at that place. The introduction of such a term satisfies a long-felt want, seeing that 'Carboniferous Limestone' lacks all definiteness. In the South-Western Province 'Carboniferous Limestone' only denotes a portion (and that a variable portion) of the sequence. Outside the South-Western Province the use of the term is hopelessly misleading, since it suggests a correlation which is often entirely false (for example, the 'base of the Carboniferous Limestone' may be a deposit of *Dibunophyllum*-age).

Dr. Matley stated that he had invited the attention of geologists to the peculiar stratigraphy of the limestone-bands in the Rush Slates, as he thought that they might throw some light on the structure of 'limestone-knolls' referred to by the President. He hoped, before long, to complete the examination of the coast-section nearer Skerries, and then he might be able to ascertain definitely the horizon of the second conglomerate near that locality, which he thought at present belonged to a horizon higher than that of the Rush Conglomerate.

In reply to Mr. Ussher, the speaker stated that the thickness of the beds as shown in the vertical section was thought to be approximately correct; but, owing to the obscurity of the dip in places, some modification of the estimate given in the paper might be necessary.

[1] See Renevier's 'Chronographe Géologique,' 2nd ed. 1897.
[2] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 264.

14. *On the* Carboniferous Limestone (Avonian) *of the* Mendip Area (Somerset), *with especial reference to the* Palæontological Sequence. By Thomas Franklin Sibly, B.Sc., F.G.S. (Read February 7th, 1906.)

[Plates XXXI–XXXV.]

Contents.

I. Introduction.

This paper contains the results of a detailed examination of the Carboniferous Limestone in the Mendip area.

The object of my work has been the complete investigation of the faunal sequence in the Carboniferous-Limestone Series, following on the lines laid down by Dr. Arthur Vaughan, in his great paper [1] on 'The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area.' Detailed work in the Mendips has shown that the system of zones and subzones, established by Dr. Vaughan in the Bristol sequence, requires only very slight modification to co-ordinate accurately the faunal sequence in the Mendip area. The correlation of the Mendip and Bristol areas is treated fully in the present paper, my comparison being based on Dr. Vaughan's paper, to which I make frequent reference.

I am indebted to Mr. H. B. Woodward's Geological Survey-memoir on 'The Geology of East Somerset & the Bristol Coalfields,' published in 1876, and to a paper by Prof. C. Lloyd Morgan, entitled 'Mendip Notes,' published in the Proceedings of the Bristol Naturalists' Society,[2] for much valuable information and guidance. To my recent paper [3] on 'The Carboniferous Limestone of Burrington Combe,' which deals fully with the Burrington section, I refer frequently.

The Carboniferous Limestone presents more or less complex structural features in several parts of the Mendip area, and it is to be hoped that the application of palæontological study to these problems will furnish correct solutions. The time at my disposal has

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 181–305.
[2] N. s. vol. vi (1890–91) pp. 169–82.
[3] Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. 1, 1905 (issued for 1904) pp. 14–41.

not permitted me to pay much attention to this part of the subject. But to one of these problems, namely, the geology of the Ebbor-Rocks district, a subject which has received attention from several previous writers, I have devoted a considerable amount of time. The features of this locality are especially interesting, and I have described them in a separate note.

Throughout the paper, I have adhered to the system of nomenclature of corals and brachiopods employed by Dr. A. Vaughan and defined in the introduction[1] to his paper. The palæontological notes and plates[2] accompanying Dr. Vaughan's paper, taken in conjunction with the notes and plates which I have appended to the present paper, will explain my faunal lists.

Following the suggestion made[3] by Dr. Vaughan, I have adopted the term Avonian to connote the whole Carboniferous-Limestone Series, as developed in the South-West of England and South Wales, and the terms Clevedonian and Kidwellian for the lower and upper divisions, respectively, of the Avonian. The use of these terms secures a highly-desirable definiteness, and avoids the possibility of any confusion such as might arise from comparisons, based on lithological divisions only, with the Carboniferous rocks of other areas. The distinctness of the Clevedonian and Kidwellian faunas, which is a well-defined feature in the Mendips, as in the Bristol area, is demonstrated in a separate note.

The series of zones and subzones in the Avonian of the Mendip area is as follows:—

	Zones.	*Subzones & Horizons.*	*Approximate thickness in feet.*
KIDWELLIAN.	*Dibunophyllum*	(D_2) *Lonsdalia floriformis.* (D_1) *Dibunophyllum θ.*	500
	Seminula	(S_2) *Productus* aff. *Cora*, mut. S_2. (S_1) *Productus* cf. *semireticulatus*, mut. S_1.	720
CLEVEDONIAN.	*Syringothyris*	(C) *Syringothyris* aff. *cuspidata*, mut. C.	550
		γ	
	Zaphrentis	(Z_2) *Zaphrentis* aff. *cornucopiæ.* (Z_1) *Spirifer* aff. *clathratus.*	800
		β	
	Cleistopora	(K_2) *Spiriferina* cf. *octoplicata.* (K_1) *Productus bassus.* (M) (*Modiola*-phase.)	450
			3020

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 183, 184.
[2] *Ibid.* pp. 266–303 & pls. xxii–xxvi.
[3] *Ibid.* p. 264.

My sincere thanks are due to those geologists who have so readily assisted me in my investigations. To Dr. A. Vaughan I am indebted for continual encouragement, and especially for invaluable advice throughout my palæontological work. I am indebted to Mr. H. E. Balch for very kindly placing his knowledge of the Wells district at my service, and particularly for the great assistance which he has given me in the examination of the Ebbor-Rocks district. I have to thank Dr. Wheelton Hind for naming lamellibranchs and gasteropods; and Prof. S. H. Reynolds and Mr. F. P. Burt for valuable assistance in the field. To Mr. J. W. Tutcher I am under a deep obligation, for the trouble which he has taken in the preparation of the excellent photographs (reproduced in Pls. XXXI & XXXII) illustrating this paper.

II. The Faunal Sequence in the Mendip Area.

Clevedonian or Lower Avonian (Lower Carboniferous Limestone).

K = Zone of *Cleistopora* aff. *geometrica* [*Cleistopora*-Zone] (including *Modiola*-phase M).

General lithological character.—Shales with subsidiary limestones in the lower part; thick shales in the middle part; alternating shales and limestones in the upper part.

Coral-fauna:

Cleistopora aff. *geometrica*.

Brachiopod-fauna:

Athyris Royssii muts.
Athyris (Actinoconchus) cf. *lamellosa*.
Reticularia cf. *reticulata*.
Spirifer aff. *clathratus* & var.
Spiriferina cf. *octoplicata*.
Syringothyris aff. *cuspidata*, mut. K.
Eumetria aff. *carbonaria*.
Camarotœchia mitcheldeanensis.
Leptæna analoga.

Orthothetes aff. *crenistria*, muts.
Rhipidomella aff. *Michelini*.
Productus bassus.
Productus cf. *Martini*.
Chonetes 'Buchiana' } & intermediate forms.
Chonetes cf. *crassistria* } & intermediate forms.
Chonetes cf. *hardrensis*.
(Discina) sp.

Other groups:

Lamellibranchiata.
Modioliform lamellibranchs.
Parallelodon sp.
Gasteropoda.
Bellerophon sp.
Capulus cf. *inæqualis*.

Bryozoa.
Rhabdomeson spp.
Fenestellids.
Ostracoda—several forms.

Subdivisions:—

M = *Modiola*-phase.

This includes only the lowest part of the series, and exhibits the gradual establishment of the *Cleistopora*-fauna.

Very characteristic features of this phase are the common occurrence of Modioliform lamellibranchs and the great abundance of ostracods at recurring levels. The brachiopod-fauna includes *Chonetes* cf. *hardrensis* (abundant), *Ch.* cf. *crassistria*, *Athyris Royssii* (common), *Orthothetes* aff. *crenistria*, *Spirifer* aff. *clathratus*, *Camarotœchia* aff. *mitcheldeanensis*, and *(Discina)* sp. *Bellerophon* sp. occurs abundantly.

Although the development of this phase at the base of the Avonian sequence constitutes a persistent and important feature, yet the faunal characters of the series do not justify its separation as a distinct zone, and it must, therefore, be regarded as the initial, shallow-water phase of the *Cleistopora*-Zone.

At the top of the series occur characteristic red limestones, mainly composed of crinoid-débris, but containing abundant *Rhabdomeson*. (The 'Bryozoa-Beds.')

K_1 = Subzone of *Productus bassus*. (BASSUS-subzone.)

This forms the lowest portion of the main zone, and is characterized by the great abundance of:—

Camarotœchia mitcheldeanensis, *Orthothetes* aff. *crenistria*, mut. K_1, *Productus bassus*, and *Chonetes* '*Buchiana*.'

Chonetes cf. *hardrensis* occurs abundantly.

Eumetria aff. *carbonaria* occurs not uncommonly, and is, apparently, confined to this subzone.

Athyris Royssii, *Reticularia* cf. *reticulata*, *Rhipidomella* aff. *Michelini*, *Syringothyris* aff. *cuspidata*, mut. K, and *Spirifer* aff. *clathratus* range throughout, and the latter fossil becomes abundant at the top of the subzone.

Productus cf. *Martini* occurs sparingly in the uppermost beds.

The gasteropod *Capulus* cf. *inæqualis* is abundant in the lower beds. Bryozoans (*Rhabdomeson*) are abundant.

K_2 = Subzone of *Spiriferina* cf. *octoplicata*. (OCTOPLICATA-subzone.)

This includes the uppermost portion of the zone, as well as the horizon of overlap with the *Zaphrentis*-Zone (Horizon β).

The special features of this subzone are:—

(1) The occurrence of *Spiriferina* cf. *octoplicata*, which attains its maximum at the top, and has not been recorded outside the subzone.
(2) The increasing abundance of *Spirifer* aff. *clathratus* and var., *Productus* cf. *Martini*, *Rhipidomella* aff. *Michelini*, and *Chonetes* cf. *hardrensis*.
(3) The common occurrence of *Athyris (Actinoconchus)* cf. *lamellosa*.

Orthothetes aff. *crenistria*, which shows a mutational change, is extremely abundant throughout.

Syringothyris aff. *cuspidata*, mut. K, attains its maximum in the lowest part of this subzone, and persists abundantly throughout.

Reticularia cf. *reticulata* and *Athyris Royssii* occur commonly throughout.

Camarotœchia mitcheldeanensis, though still abundant, is greatly diminished in numbers.

Productus bassus occurs rarely.

Chonetes '*Buchiana*' is replaced, as an abundant form, by *Ch.* cf. *crassistria*.

Cleistopora aff. *geometrica* occurs in this subzone, but is nowhere common.

Between the well-marked *bassus*- and *octoplicata*-subzones, occurs a thick series of shales, which may be assigned equally well to either subzone, since it does not possess the characteristic features of either one. This part of the zone is marked by the great abundance of a *Chonetes*, intermediate between *Ch.* '*Buchiana*' and *Ch.* cf. *crassistria*.

Z = Zone of *Zaphrentis* aff. *Phillipsi*.
(*Zaphrentis*-Zone.)

General lithological character.—Massive limestones, including much highly-crinoidal 'black rock.' In the lowest part of the zone thin shales are interbedded with the limestones. Much nodular and lenticular chert occurs, being most strongly developed in the middle and upper portions of the zone.

Coral-fauna:

Zaphrentis aff. *Phillipsi*.
Zaphrentis aff. *cornucopiæ*.
Caninia cylindrica.
Cyathophyllum θ.
Amplexus cf. *coralloides*.
Michelinia cf. *favosa*.
Michelinia cf. *tenuisepta*.
Syringopora θ.
Syringopora cf. *reticulata*.

Brachiopod-fauna:

Athyris Royssii.
Athyris cf. *glabristria*, muts.
Martinia cf. *linguifera*.
Reticularia cf. *reticulata*.
Spirifer aff. *clathratus* & var.
Spirifer cf. *cinctus*.
Spiriferina cf. *octoplicata*.
Syringothyris aff. *cuspidata*, mut. K.
Syringothyris aff. *cuspidata*, mut. C.
Syringothyris aff. *laminosa*.
Camarotœchia aff. *mitcheldeanensis*.
Pugnax cf. *pugnus*.
Leptæna analoga.
Orthothetes aff. *crenistria*, muts.
Rhipidomella aff. *Michelini*.
Schizophoria aff. *resupinata*.
Productus cf. *Martini*.
Productus cf. *semireticulatus*.
Productus aff. *pustulosus*.
Productus cf. *aculeatus*.
Productus aff. *Cora*, mut.
Chonetes cf. *hardrensis*.
Chonetes cf. *papilionacea*.

Subdivisions:—

β = Horizon β.

This includes only the lowest beds of the zone. It is defined by the association of *Zaphrentis* aff. *Phillipsi* and *Spiriferina* cf. *octoplicata*, and thus forms a horizon of overlap between the *Zaphrentis*- and *Cleistopora*-Zones. Since its palæontological characters, excepting

only the occurrence of *Spiriferina* cf. *octoplicata*, are precisely those of the lower part of the *Zaphrentis*-Zone, it is better regarded as the base of that zone than as the top of the *Cleistopora*-Zone.

Z_1 = Subzone of *Spirifer* aff. *clathratus*. (CLATHRATUS-subzone.)

Special faunal characters:—

Corals:

Zaphrentis aff. *Phillipsi* occurs commonly in the lower part.

Michelinia cf. *favosa* enters at Horizon β, and is abundant at certain levels.

Syringopora θ occurs rarely in the uppermost beds.

Brachiopods:

Spirifer aff. *clathratus* and var. are enormously abundant at recurring levels throughout.

Chonetes cf. *hardrensis*, in the mutation characteristic of the *Cleistopora*-Zone and this subzone, *Productus* cf. *Martini*, *Rhipidomella* aff. *Michelini*, and *Reticularia* cf. *reticulata* attain their maxima.

Orthothetes aff. *crenistria*, in a characteristic mutation, is enormously abundant at certain levels.

Athyris Royssii, mut. β, occurs at the base of this subzone, but is not abundant. *A.* cf. *glabristria*, mut. Z_1, and *Syringothyris* aff. *cuspidata*, mut. K, are abundant. *Leptæna analoga* is abundant at certain levels, and attains a maximum.

Productus aff. *pustulosus* occurs commonly. *Productus* aff. *Cora*, mut., occurs very rarely.

Camarotœchia mitcheldeanensis is comparatively rare above Horizon β. *Syringothyris* aff. *laminosa* is rare. *Chonetes* cf. *papilionacea* enters sparingly in the upper part of the subzone.

Z_2 = Subzone of *Zaphrentis* aff. *cornucopiæ*. (CORNUCOPIÆ-subzone.)

This forms the upper half of the zone, and includes the horizon of overlap with the *Syringothyris*-Zone (Horizon γ).

Special faunal characters:—

Corals:

The most important feature of this subzone is the great abundance of *Zaphrentis* aff. *cornucopiæ* and *Z.* aff. *Phillipsi*, both of which attain their maxima in the upper part.

Caninia cylindrica enters early in the subzone, and soon becomes fairly abundant; it attains a maximum at Horizon γ, where it is extraordinarily abundant.

Amplexus cf. *coralloides*, which is apparently confined to this subzone, occurs very commonly when at a maximum.

Michelinia cf. *favosa* attains a second maximum in the lower part of this subzone, where it is prolific; but afterwards declines rapidly, and does not range above Horizon γ. *M.* cf. *tenuisepta* probably occurs in this subzone.[1]

Syringopora θ is characteristic, and very common at certain levels. *S.* cf. *reticulata* first occurs at Horizon γ.

Cyathophyllum θ occurs in this subzone.

Brachiopods:

Spirifer aff. *clathratus* and var., though greatly diminished in numbers, persist abundantly throughout the subzone. *Sp.* cf. *cinctus* occurs not uncommonly.

Syringothyris aff. *laminosa* attains its maximum. *S.* aff. *cuspidata*, mut. C, enters, and increases in abundance towards the top.

Orthothetes aff. *crenistria* (especially in the mut. Z), is extremely abundant throughout.

Leptæna analoga attains a second maximum, and occurs commonly up to Horizon γ.

Athyris cf. *glabristria*, mut. Z_2, is abundant, and *Reticularia* cf. *reticulata* occurs commonly; but *Athyris Royssii* is very rare.

Rhipidomella aff. *Michelini* occurs commonly throughout. *Schizophoria* aff. *resupinata* enters, and can be found occasionally throughout the subzone, but is never abundant below Horizon γ.

Productus cf. *Martini* is not uncommon. *Pr.* cf. *semireticulatus* occurs sparingly below Horizon γ, but is not uncommon at that level. *Pr.* aff. *pustulosus* ranges throughout; the most typical form occurs commonly at Horizon γ.

Chonetes cf. *hardrensis* is much diminished in numbers, but is still abundant at recurring levels throughout. *Ch.* cf. *papilionacea* gradually increases in numbers, and is abundant at Horizon γ.

Martinia cf. *linguifera*,[2] *Pugnax* cf. *pugnus*,[2] and *Productus* cf. *aculeatus* occur very rarely in this subzone.

γ = Horizon γ.

This includes the uppermost part of the zone, and exhibits an overlap of the *Zaphrentis*- and *Syringothyris*-faunas. The outstanding palæontological feature of this horizon is the extreme abundance of *Caninia cylindrica*, mut. γ.

Horizon γ must be regarded as the top of the *Zaphrentis*-Zone,

[1] The specimen of *Michelinia tenuisepta* figured by Edwards & Haime, 'Monogr. Brit. Foss. Corals' (Palæont. Soc.) pt. iii (1852) pl. xliv, fig. 1, and preserved in the Bristol Museum, was obtained from the Mendips, near Maesbury.

[2] Identical forms occur at the same horizon in the Carboniferous Limestone of Freshwater West, near Pembroke (South Wales). I have had the opportunity of comparing the specimens from this locality, collected by Mr. A. L. Leach, of Tenby, with my own specimens.

rather than as the base of the *Syringothyris*-Zone, for the following reasons:

(1) The brachiopod-fauna is, as a whole, essentially similar to that of the Upper *Zaphrentis*-Zone. Special points of resemblance are: the abundance of *Spirifer* aff. *clathratus* and var. and *Chonetes* cf. *hardrensis*, and the common occurrence of *Leptæna analoga* and *Productus* aff. *pustulosus*.

(2) *Zaphrentis* aff. *Phillipsi* and *Z.* aff. *cornucopiæ*, which are both abundant at this horizon, are essentially *Zaphrentis*-Zone forms, being very rare in the *Syringothyris*-Zone. (The mutation of *Zaphrentis* aff. *cornucopiæ*, which occurs commonly in the latter zone, is easily distinguished from the typical Z_2 form.)

The special faunal characters, which Horizon γ possesses in common with the *Syringothyris*-Zone, are the following:

(1) The common occurrence of *Syringothyris* aff. *cuspidata*, mut. C.
(2) The abundance of *Orthothetes* aff. *crenistria*, mut. C.
(3) The abundance of *Schizophoria* aff. *resupinata*. (This form attains its maximum immediately above Horizon γ.)
(4) The occurrence of *Caninia cylindrica*. (*Caninia cylindrica* persists throughout the *Syringothyris*-Zone.)
(5) The occurrence of *Syringopora* cf. *reticulata*.

C = Zone of *Syringothyris* aff. *cuspidata*, mut. C. (*Syringothyris*-Zone.)

General lithological character.—Massive limestones. The lowest beds are slightly dolomitic, but the main part of the zone consists of fairly-pure[1] limestones, which are more or less oolitic, the local development of oolites being sometimes considerable.

Coral-fauna (omitting Horizon γ):

Zaphrentis aff. *Phillipsi*.
Zaphrentis aff. *cornucopiæ*, mut. C.
Caninina cylindrica, muts.
Caninoid *Cyathophylla*.
Cyathophyllum ϕ.
Campophyllum caninoides.
Amplexus sp.
Michelinia megastoma.
Syringopora cf. *reticulata*.
Syringopora cf. *distans*.
Lithostrotion cf. *irregulare*.
Early Clisiophyllids.

Brachiopod-fauna (omitting Horizon γ):

Seminula ambigua.
Seminula aff. *ficoides*.
Athyris cf. *expansa*.
Athyris cf. *glabristria*.
Reticularia cf. *reticulata*.
Spirifer aff. *clathratus*.
Spirifer cf. *bisulcatus*.
Spirifer cf. *striatus*.
Syringothyris aff. *cuspidata*, mut. C.
Syringothyris aff. *laminosa*.
Pugnax cf. *acuminatus*.
Orthothetes aff. *crenistria*, mut. C.
Rhipidomella aff. *Michelini*.
Schizophoria aff. *resupinata*.
Derbya sp.
Productus concinno-Martini.
Productus aff. *Cora*, mut. C.
Productus θ.
Productus pustuloso-fimbriatus.
Chonetes cf. *hardrensis*.
Chonetes cf. *papilionacea*.
Chonetes cf. *comoides*.

Subdivisions.—None; excluding Horizon γ, which is best regarded as the top of the *Zaphrentis*-Zone (see above, p. 330).

[1] The limestones of this zone are extensively burnt for lime.

Special faunal characters:—

Corals:

The zone is specially characterized by:—

(1) The common occurrence, at recurring levels, of *Caninia cylindrica*, muts. (especially mut. S_1, in the uppermost part), Caninoid *Cyathophylla*, and Caninoid *Campophylla*; and of *Cyathophyllum* ϕ, which ranges throughout the upper and main part, and attains its maximum in the uppermost beds.
(2) *Michelinia megastoma*, which is abundant in the lower part, and has not been recorded outside this zone.
(3) *Syringopora* cf. *reticulata*, which, as an abundant form, is highly characteristic of the lower part of the zone, although it ranges throughout and persists into the succeeding subzone.

Zaphrentis aff. *cornucopiæ*, mut. C, is characteristic, and has been recorded throughout the greater part of the zone. *Z.* aff. *Phillipsi* occurs only in the lowest part of the zone.

Amplexus sp. occurs somewhat rarely.

Early Clisiophyllids occur very rarely.

Lithostrotion cf. *irregulare*, which is the first representative of the genus, occurs in the topmost beds.

Brachiopods:

The zone is specially characterized by:—

(1) The maximum of *Syringothyris* aff. *cuspidata*, mut. C. This mutation ranges throughout, but it is very scarce in the uppermost beds,
(2) The great abundance of *Orthothetes* aff. *crenistria*, mut. C, at recurring levels throughout.
(3) *Productus concinno-Martini*, which is common throughout the main part.
(4) The abundance of *Chonetes* cf. *comoides* at certain levels, especially in the lower part.

Spirifer aff. *clathratus* persists throughout the main part of the zone, and is not uncommon in the lower part. *Sp.* cf. *bisulcatus* is not uncommon in the upper and main portions.

Syringothyris aff. *laminosa* occurs very sparingly throughout.

Athyris cf. *expansa* is common throughout the upper and main portion of the zone. *Reticularia* cf. *reticulata* ranges throughout, and is common at certain levels.

Seminula ambigua is characteristic of the upper part of the zone. *S.* aff. *ficoides* enters sparingly in the uppermost beds.

Schizophoria aff. *resupinata* attains its maximum immediately above Horizon γ, and is there very prolific, but it does not persist far into the zone. *Rhipidomella* aff. *Michelini*, although greatly diminished in numbers, persists commonly throughout.

Productus aff. *Cora*, mut. C, which is characteristic of this zone and the succeeding subzone, attains its maximum. *Pr.* θ enters, and can be found occasionally throughout the upper and main part; it is locally abundant at certain levels.

Chonetes cf. *papilionacea* occurs very abundantly at numerous levels throughout. *Ch.* cf. *hardrensis* is nowhere common, and does not extend into the uppermost beds.

The abundance of large gasteropods, of the genera *Bellerophon* and *Euomphalus*, is a very noticeable feature at certain levels in this zone, particularly in the upper part.

Kidwellian or Upper Avonian (Upper Carboniferous Limestone).

S = Zone of *Seminula ficoides* and its allies. (*Seminula*-Zone.)

The lithological and palæontological characters of this zone are best treated under the separate subzones.

S_1 = Subzone of *Productus* cf. *semireticulatus*, mut. S_1. (*semireticulatus*-subzone.)

General lithological character.—Massive limestones, with thin shale-partings frequently developed. The limestones are extremely variable in character; locally, they are slightly dolomitic in the lower part of the subzone. Hard, black limestones, with abundant nodular and lenticular chert, form a very characteristic feature in the uppermost part of the subzone.

Special faunal characters:—

This subzone is characterized by the association of certain Clevedonian forms with the Lower Kidwellian fauna.

Corals:

Caninia cylindrica, mut. S_1, occurs in this subzone.

Cyathophyllum ϕ is common in the lower part, and probably ranges throughout.

Lithostrotion Martini enters abundantly at the base, and is the dominant coral throughout.

Lithostrotion basaltiforme, var. *bristolense*, occurs.

Syringopora cf. *reticulata* still occurs, but *S.* cf. *distans* has replaced it as an abundant form.

Carcinophyllum mendipense is highly characteristic of this subzone; locally, it is extremely abundant at the base.

Cyathophylloid Clisiophyllids are not uncommon.

Alveolites sp. is very rare.

Brachiopods:

Seminula ficoides and vars. occur very abundantly at certain levels; but these forms are no more prominent than *Athyris* cf. *glabristria*, mut. S_1, which locally is extremely abundant at the base, and *A.* cf. *expansa*, which ranges throughout and is abundant at certain levels.

Athyris cf. *planosulcata* is not uncommon. *Reticularia* cf. *reticulata* occurs rarely in the lowest part.

Spirifer cf. *bisulcatus* occurs locally at some levels. *Sp.* cf. *furcatus* and *Camarophoria isorhyncha* are locally abundant at the base.

Orthothetes aff. *crenistria*, mut. C, occurs not uncommonly throughout, and is abundant at the top of the subzone.

A well-marked, spinous mutation of *Productus concinno-Martini* (= *Pr.* cf. *semireticulatus*, mut. S_1) is abundant in the upper part of the subzone.

Productus aff. *Cora*, mut. C, occurs occasionally. *Pr.* θ is abundant at certain levels, and extremely prolific in the topmost beds. *Pr.* aff. *hemisphericus* is not uncommon. *Pr. punctatus* has been recorded [1] in this subzone. Specimens of a fimbriate *Productus* occur not uncommonly.

Chonetes cf. *papilionacea* is prolific in the upper part, and is associated, in the uppermost beds, with abundant specimens of *Ch.* aff. *comoides*.

Dielasma cf. *hastata* and *Pugnax* cf. *angulatus* occur very rarely in this subzone.

S_2 = Subzone of *Productus* aff. *Cora*, mut. S_2. (CORA-subzone.)

General lithological character.—Massive limestones, consisting mainly of beds which are dark blue-grey or black in colour and very compact in texture.

The fauna of this subzone contrasts strongly with that of the preceding subzone, for, although abundant in individuals, it is poor in species.

Coral-fauna:

Lithostrotion Martini and variants. Very abundant throughout the greater part.

Syringopora cf. *distans*.	Occasional.
Syringopora cf. *geniculata*.	Occasional.
Carcinophyllum aff. θ.	Occasional.
Cyathophyllum Murchisoni (?)	Occasional.

Brachiopod-fauna:

Seminula ficoides and closely-allied forms.	Very abundant throughout the greater part.
Productus aff. *Cora*, mut. S_2, and variants.	Very abundant throughout the greater part.

Productus aff. *hemisphericus*, increasing in numbers.
Productus '*giganteus*,' abundant in the topmost beds.
Chonetes cf. *papilionacea*, abundant at recurring levels.
Chonetes aff. *comoides*.
Orthothetes aff. *crenistria*, rare.
Cyrtina aff. *carbonaria* occurs in the lower part.

The subzone is especially characterized by *Productus* aff. *Cora*, mut. S_2, and by the maximum of *Seminula*.

[1] *Productus punctatus* is abundant at the base of S_1 in the Weston-super-Mare district, but I have failed to record it at the same horizon in the Mendip area.

D = Zone of *Dibunophyllum* aff. *turbinatum*.
(*Dibunophyllum*-Zone.)

General lithological character.—Massive limestones, with some rubbly limestones, and subsidiary shales.

Coral-fauna:

Alveolites septosa.
Syringopora cf. *distans*.
Syringopora cf. *geniculata*.
Syringopora cf. *ramulosa*.
Lithostrotion Martini and variants.
Lithostrotion irregulare.
Lithostrotion Portlocki.
Cyathophyllum Murchisoni and variants.
Koninckophylloid *Cyathophylla*.
Campophyllum spp.
Clisiophyllids of numerous types, such as *Carcinophyllum* θ, the group of *Dibunophyllum* aff. *turbinatum*, and *Cyclophyllum*.
Lonsdalia floriformis.

Brachiopod-fauna:

Seminula aff. *ficoides*.
Athyris cf. *expansa*.
Athyris cf. *planosulcata*.
Martinia aff. *lineata*.
Spirifer cf. *bisulcatus*.
Cyrtina sp.
Orthothetes aff. *crenistria*.
Derbya aff. *senilis*.
Rhipidomella sp.
Productus aff. *Cora*, muts.
Productus hemisphericus and vars.
Productus ϕ.
Productus giganteus.
Productus cf. *latissimus*.
Productus concinnus, mut. D_2, and vars.
Productus aff. *scabriculus*.
Productus punctato-fimbriatus, including *Pr.* aff. *elegans*.
Productus sp., convergent with *Pr. margaritaceus*.
Chonetes aff. *comoides*.

Subdivisions:—

D_1 = Subzone of *Dibunophyllum* θ and *Dibunophyllum* ϕ.
($\theta\phi$-subzone.)

Special faunal characters:—

Corals:

The subzone is especially characterized by:—

(1) The numerical maximum of the Clisiophyllids. The most abundant forms are *Carcinophyllum* θ, *Dibunophyllum* θ, and *D.* ϕ.
(2) The great abundance of *Cyathophyllum Murchisoni* and its variants.

Clisiophyllum aff. *curkeenense* occurs in this subzone.

Lithostrotion Martini and its variants are still common, though greatly reduced in numbers.

Alveolites septosa is abundant.

Campophyllum sp. and Koninckophylloid *Cyathophylla* occur.

The species of *Syringopora* include *S.* cf. *geniculata*, *S.* cf. *distans*, and *S.* cf. *ramulosa*; of these, the first is the most abundant.

Brachiopods:

The subzone is especially characterized by the great abundance of *Productus* '*giganteus*,' *Pr. hemisphericus*, and *Chonetes* aff. *comoides*.

Variants of *Productus hemisphericus* are common. *Pr.* aff. *Cora* is abundant in a characteristic mutation. *Pr.* aff. *elegans* occurs rarely.

Athyris cf. *expansa* and *Derbya* aff. *senilis* are common.

Seminula is uncommon. *Martinia* aff. *lineata*, *Orthothetes*, and *Cyrtina* are rare.

D_2 = Subzone of *Lonsdalia floriformis*. (*Lonsdalia*-subzone.)

Special faunal characters:—

Corals:

Lonsdalia floriformis and *Lithostrotion Portlocki* are highly characteristic. *L. irregulare* is abundant. *L. Martini*, in its mutations towards *L. irregulare* and *L. Phillipsi*, is common.

Dibunophyllum ψ, *Cyclophyllum pachyendothecum*, mut., and *Lonsdalia*-like *Carcinophylla* are common.

Cyathophyllum Murchisoni, though far less abundant than in the lower subzone, is still common.

Koninckophylloid *Cyathophylla* and a Campophyllid occur in this subzone.

Syringopora cf. *distans* is fairly abundant.

Brachiopods:

Productus ϕ is characteristic and very abundant. *Pr. concinnus*, mut. D_2, is characteristic, and occurs very abundantly in the upper beds; *costatus*-like variants of this form are abundant.

Productus hemisphericus is uncommon. *Pr.* sp., convergent with *Pr. margaritaceus*, occurs in the upper part of the subzone. *Pr. punctato-fimbriatus* and *Pr.* cf. *latissimus* occur commonly.

Productus aff. *scabriculus* is not uncommon.

Chonetes aff. *comoides*, in a mutation possessing accentuated Productoid characters, is abundant at certain levels.

Derbya aff. *senilis*, *Athyris* cf. *expansa*, *A.* cf. *planosulcata*, *Martinia* aff. *lineata*, *Spirifer* cf. *bisulcatus*, and *Rhipidomella* sp. occur somewhat rarely.

III. General Stratigraphy of the Carboniferous Limestone in the Mendip Area.

The following general remarks are intended chiefly to explain the system on which the exposures of the Carboniferous Limestone are classified in this paper.

Broadly considered, the stratigraphy of the Carboniferous Limestone in the Mendip area has been determined by elevation along four main axes, each of which runs in an easterly and westerly direction. The Carboniferous Limestone of the main Mendip outcrop may, then, be treated with reference to four anticlines which have an easterly and westerly trend; or rather, more

strictly speaking, with reference to four periclines, each of which has its longer axis trending approximately east and west. Denudation of the summits of these periclines has exposed the Old Red Sandstone at Black Down, North Hill, Pen Hill, and Beacon Hill (see map, Pl. XXXIII). Taken in order south-eastward, these periclines are as follows :—

(1) The Black-Down pericline, extending from near Compton Martin westward, through Black Down and Bleadon Hill to Brean Down, and finally represented, in mid-channel, by the Steep Holme.
(2) The North-Hill pericline, extending westward from Red Hill (near Emborough) through Eaker Hill and North Hill to Priddy, and still farther westward from Priddy, towards Draycott.
(3) The much-faulted pericline of Pen Hill, which extends, in a direction a little south of west, from Gurney Slade and Binegar to Pen Hill and Rookham Hill, and probably affects the ground north of the Ebbor Valley, considerably west of Rookham Hill.
(4) The Beacon-Hill pericline, extending eastward from Maesbury, through Beacon Hill, Tadhill and Little Elm, to the vicinity of Frome.

In addition to these main folds, other minor folds and many faults have affected the structure of the area. The east-and-west anticline of Tor Hill and Lyatt Hill, south of the main outcrop, is probably connected with the anticline which, according to the Geological Survey-memoir,[1] is indicated near Bowlish, immediately north of Shepton Mallet.

The existence of so many isolated masses of Carboniferous Limestone, south of the main outcrop, as at Nyland Hill, Lodge Hill, Wookey, Dulcote Hill, Worminster, etc., points to considerable disturbance, probably of a complex nature.

The important faults and fault-complexes of the Mendips are mainly confined to the eastern half of the area. The following are some of the most noteworthy :—

(1) The great thrust-fault on the south side of the Ebbor Valley, south of Priddy, which has thrown beds of the Upper *Zaphrentis*-Zone against shales of 'Millstone-Grit' age.
(2) The extensive fault, or system of faults, on the north side of the Old Red Sandstone of Pen Hill.
(3) The fault-complex of the Emborough district.
(4) The great north-and-south fault of Heale and Downhead, on the south side of the Beacon-Hill pericline, which has let down the beds on the east, and thus considerably reduced the width of the Old-Red-Sandstone outcrop north of Downhead and at Little Elm.
(5) The complex movements which have produced inliers of Carboniferous Limestone at Vobster and Luckington, in the Radstock Coalfield, north of the Mendip outcrop.

The outcrop of the uppermost part of the Avonian Series, in the Mendip area, is very limited in extent, and is chiefly confined to the district between Gurney Slade, on the west, and Mells, on the east, bordering the northern outcrop of the Millstone Grit. This is due to :—(1) The enormous amount of denudation which the district has suffered in various periods; and (2) the incomplete

[1] 'Geology of East Somerset & the Bristol Coalfields' 1876, p. 196.

removal of the covering of Triassic and Jurassic deposits. In the southern part of the area, the *Dibunophyllum*-Zone has a very small outcrop, and is exposed only at two or three points. East of Downside, as far as Heale, the northward extension of the Lias and Inferior Oolite is so great, that the outcrop of the Avonian rocks is intermittent, and is confined to the *Cleistopora*- and *Zaphrentis*-Zones. The Heale fault, by letting down the Limestone on the east, brings in the *Dibunophyllum*-Zone at Leighton, where the overlying Inferior Oolite has been removed; but, in the extreme east of the area, the Carboniferous Limestone is exposed only in the gorges of streams, which have cut through the superincumbent Oolites, as at Vallis Vale, Whatley Bottom, and Holwell Valley.

IV. Description of Exposures in the Mendip Area.

(i) Continuous Sections.

Only four sections in the Mendip area can be classed as 'continuous sections.'

(*a*) The Burrington-Combe section, on the north side of the Black-Down pericline.

In Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. 1, 1905 (issued for 1904), pp. 14–41, I have described this fine section, which affords by far the most complete sequence exposed in the Mendip area, in detail; consequently, I need only here mention its extent.

Zonal extent:—All the zones and subzones up to, and including, the base of the *Dibunophyllum*-Zone.

(*b*) The Cheddar-Gorge section, on the south side of the Black-Down pericline.

This magnificent gorge, together with the ravine which, branching off on the east side, runs northward to Long Wood, affords a fine section.

Zonal extent:—Upper *Syringothyris*-Zone, *Seminula*-Zone, and the base of the *Dibunophyllum*-Zone.

(*c*) The Maesbury railway-section, on the north-western side of the Beacon-Hill pericline.

The cutting on the Somerset & Dorset Joint Railway, north of Masbury[1] Station, affords the only really good section of the *Cleistopora*-Zone to be found in the Mendip area.

Zonal extent:—*Cleistopora*-Zone (K_1, K_2, & β) exclusive of the lowest part (M).

(*d*) The Vallis-Vale section, near Frome, on the north side of the Beacon-Hill pericline.

The numerous quarries in Vallis Vale, taken together, constitute a fairly-continuous section.

Zonal extent:—Upper *Zaphrentis*-Zone (Horizon γ not exposed), *Syringothyris*-Zone (uppermost 400 feet exposed), and the base of the *Seminula*-Zone.

[1] Misspelt thus by the railway-authorities.

(ii) Classified Lists of Exposures, arranged zonally.

In the following lists are included all those exposures in the Mendip area which I have examined personally. In the examination of so large an area in a limited space of time, it is, of course, likely that some exposures have been overlooked; and this statement applies especially to the *Cleistopora*-Zone, many exposures of which occur in by-lanes. But it is claimed that the following lists include all the quarries and important sections in the area, besides a majority of the disused quarries and isolated exposures of importance.

For convenience of reference, the exposures are assigned, so far as possible, to the several periclinal masses; exposures in the isolated masses north and south of the main outcrop are tabulated in separate sections, under their respective zones.

The column headed 'Sheet' defines the sheet of the 6-inch Ordnance-Survey map (Somerset) on which each exposure lies; while the column headed 'Horizon' contains information as to the subzonal position of the exposures, in all cases where I have been able to determine the horizon with accuracy.

Cleistopora-Zone.

Where best exposed in the Mendip area:—

(*a*) The Burrington Section.[1]
M well exposed; K_1 and K_2 poorly exposed.

(*b*) The Maesbury railway-section (Somerset & Dorset Joint Railway).
M not exposed; K_1 and K_2 splendidly exposed.

List of Exposures in the Mendip Area.

A. The Black-Down pericline.

North side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Burrington Combe..	(See below, footnote)	M, K_1, K_2	18 N.W.

South side.

South-east of Shipham.	Section in the road-cutting leading from Longbottom Farm to Trot's Corner..................................	K_2	18 S.W.

[1] See Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. 1 (1905) pp. 18–22.

B. The North-Hill pericline.

West side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
North-east of Priddy	Cutting in Nine Barrows Lane ...	M	27 N.E.

C. The Pen-Hill pericline.

West side.

Rookham Hill	Roadside exposure	K_1	28 S.W.

D. The Beacon-Hill pericline.

North-west side.

Maesbury section ...	Cutting on the Somerset & Dorset Joint Railway, north of 'Masbury' Station	K_1, K_2	41 N.E.

Zaphrentis-Zone.

Where best exposed in the Mendip Area:—

(*a*) The Burrington section.[1]

Z_1 and Z_2 (lower part) finely displayed; Horizon γ magnificently displayed.

(*b*) The Downside Quarries (Windsor-Hill Quarry, Ham-Wood Quarry, and Downside Quarry) north of Shepton Mallet; and the railway-cutting on the north side of the Windsor-Hill tunnels.

Z_1 (upper part) exposed in Windsor-Hill Quarry and in the cutting north of that quarry; Z_2 finely displayed in Ham-Wood Quarry, Downside Quarry, and in the cutting at the entrance to the tunnels.

(*c*) The Waterlip Quarries.

Horizon β and Z_1 exposed in the quarry east of the Methodist Chapel; Z_2 finely displayed in Waterlip Quarry, east of the road, and in a smaller quarry west of the road.

[1] See Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. 1 (1905) pp. 22–29.

List of Exposures in the Mendip Area.

A. The Black-Down pericline.

North side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Brean Down	Cliffs on the south side of the Down, western part	Hor. γ	16 N.W.
Uphill	Hillside section south of Uphill Quarry	Z_2	16 N.E.
	Uphill Quarry	Hor. γ (top)	16 N.E.
	Large disused quarry on the east side of the line, near Bleadon & Uphill Station (G.W.R.)	Z_2	16 N.E.
Bleadon Hill	Old quarries on the top of the hill, south of Hutton Wood	Z_2	17 N.W.
Hutton Combe	Small roadside quarry above Yew-Tree Cottage	Z_2	17 N.W.
	Old quarry beside the lane leading past Canada Farm	Z_2	17 N.W.
Sandford Hill (south side).	Old quarry at the end of Mapleton Lane, north of Star	Hor. γ	17 N.E.
Rowberrow-to-Churchill traverse.	Old quarry on the south side of the ravine, south of Dolebury Camp.	Z_1	18 N.W.
	Quarry beside the main road, and escarpment on the south side of Dolebury Camp	Z_2	18 N.W.
Burrington Combe	(See above, p. 340)	Z_1, Z_2, & Hor. γ	18 N.W.
South of Blagdon	Old quarry west of the lane leading to Middle Ellick Farm	Z_1	18 N.E.
Blagdon to Nordrach-on-Mendip.	Old quarries:—(1) roadside north of Paywell Farm; (2) beside lane, west of the road, south-east of Paywell Farm	Z_1	18 S.E.

South side.

Bleadon	Section on the western side of Purn Hill, west of Bleadon	Z_2 & γ	16 S.E.
	Ravine running into the hill in a north-easterly direction, north of the village	Z_2 & γ	16 S.E.
North-west of Christon.	Cutting at the side of a lane on the south-eastern edge of Christon Plantation	Z_2	17 N.W.
	Old quarry at the side of the road to Hutton, at the western edge of Higher Leaze	Z_2	17 S.W.
North side of Crook Peak.	Quarry at the side of the road leading from Webbington to Winscombe	Z_2	17 S.W.

Locality.	Description.	Horizon.	Sheet.
North-east of Axbridge.	Field-exposures on the east side of the road leading to Shipham, north of the quarries	Z_2 (upper)	18 S.W.
South of Black Down, between Shipham and Charterhouse.	Quarry at Trot's Corner, south-east of Longbottom Farm	Hor. β	18 S.W.
	Quarry in a field south-west of Tyning's Farm	Z_1	18 S.W.
	Quarry close to Long-House Barn, north of Piney-Sleight Farm ...	Z_2	18 S.W.
Charterhouse	Two quarries on the north side of the valley; respectively west and east of the Priddy road ...	Z_1	18 S.E.
Nordrach-on-Mendip.	Old quarry in a field north of the Sanatorium	Z_1	18 S.E.

B. Isolated exposure south of the Black-Down pericline, and west of the North-Hill pericline.

South-east of Cheddar.	Old quarry in a field, in the northern angle of the cross-roads, north-east of Lyde Farm.	probably Z_1	27 N.W.

C. The North-Hill pericline.

North side.

West End	Old quarry on the north side of the road, a little east of Eaker-Hill Farm	Hor. γ	28 N.W.

West side.

North-west of Priddy.	Old quarry on the north side of the Cheddar road, 400 yards west of Townsend Pool	Z_2	27 N.E.
North of Priddy ...	Old quarry in a yard at Townsend.	Z_1	27 N.E.
East of Priddy	Old quarry on the east side of Eastwater Drove	Z_1 (lower)	27 N.E.

South side.

East of Priddy	St. Cuthbert's Lead-Works; broken ground and trenches	Z_1	28 S.W.
North of Pen Hill .	Old quarry in a field on the west side of Sideling Plantation	Hor. γ	28 S.W.
Green Ore	Old quarry on the west side of the Bath-Wells road, 600 yards northward from the Green-Ore cross-roads	Z_2	28 S.W.

D. The Pen-Hill pericline.

North side (faulted).

Locality.	Description.	Horizon.	Sheet.
Hill Grove	Exposures in Valley Wood	Z_2	28 S.W.

West side.

Rookham Hill	Escarpment on the west side of the road	Z_1	28 S.W.

South side.

Horrington Hill ...	Old quarry under the ridge, north-east of West Horrington	Z_2	41 N.W.
	Quarries:—(1) close to the road at Paradise Cottage; (2) at the roadside farther up the hill ...	Z_2	28 S.W.
South of West Horrington.	Quarry at the roadside, immediately north of the Somerset & Bath Lunatic Asylum	Hor. γ	41 N.W.

Isolated exposure in faulted ground, west of the Pen-Hill pericline.

South of the Millstone Grit of the Ebbor Valley.	Several exposures on high ground, east of the footpath leading from Lynchcombe Lane (Westbury) towards Priddy.....................	Z_2	27 S.E.

E. Between the Pen-Hill pericline and the Beacon-Hill pericline.

West of 'Masbury' Station.	Stony-Bottom Quarry (disused)...	Hor. γ	41 N.E.
	Blackheath Quarry	Z_2	41 N.E.
	Quarry in a field, 400 yards south of Slab House	Z_2	28 S.E.

F. The Beacon-Hill pericline.

North side.

Stoke Lane	Quarry in the village, 60 yards north-west of the church	Z_2	42 N.W.
Whatley	Quarry by the roadside, on the south side of Whatley Bottom .	Z_2	30 S.W.
Vallis Vale, near Frome.	The southern end of the vale: several small adjacent quarries on the west side, and a large quarry on the east side	Z_2	30 S.W.

North-west side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Maesbury section ...	Cutting on the S. & D. J. Railway, north of 'Masbury' Station; northern end of the section......	Hor. β	41 N.E.

South-west side.

Thrupe	Old quarry by the roadside, immediately north of Thrupe-Lane Farm	Z_2	41 N.E.
North of Shepton Mallet.	The Downside Quarries, and railway-cutting north of the Windsor-Hill tunnels (see above, p. 340)	Z_1 & Z_2	41 N.E.

South side.

Waterlip	The Waterlip Quarries (see above, p. 340) and an old quarry west of the Methodist Chapel	β, Z_1, Z_2	42 N.W. & S.W.
Near Downhead ...	Small roadside quarry, 70 yards south of the Methodist Chapel, between Heale and Downhead..	Z_2	42 N.E.

G. Isolated mass south of the main outcrop.

Friar's Oven, south-east of Croscombe.	Exposure on the north-western flank of the hill, close to the railway.	Z_2	41 S.E.

Syringothyris-Zone.

Where best exposed in the Mendip area :—

(*a*) The Burrington section.[1]

Complete exposure of the whole zone.

(*b*) Brean Down.

The greater part of the zone, from Horizon γ upward, is finely displayed in the cliffs all round the Down, and in the several quarries.

(*c*) Uphill Quarry.

The lowest 100 feet of the zone, finely exposed.

(*d*) Bleadon—The Little Down Quarries.

The two northern quarries afford a continuous section of the middle part of the zone, the total vertical thickness

[1] See Proc. Bristol Nat. Soc. sér. 4, vol. i, pt. 1 (1905) pp. 29–35.

exposed being about 250 feet. The southernmost quarry, now long disused, shows a level at the top of the zone.

(*e*) Vallis Vale, near Frome.

Four quarries, in the northern part of the Vale—two on the western side, and two on the eastern—afford a discontinuous section, which extends about 400 feet downward through the zone.

List of Exposures in the Mendip Area.

NOTE :—There is no palæontological subdivision of this zone ; the symbols C_1 and C_2 are employed to denote lower and upper parts of the zone respectively.

A. The Black-Down pericline.

North side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Brean Down	Cliffs all round the Down; and two quarries on the north side, western end	C_1–C_2	16 N.W. & N.E.
Uphill	Uphill Quarry	C_1	16 N.E.
	Old quarry by the roadside in the village		
Hutton	Quarry just off the Banwell road, near Lower Canada, east of Hutton	C_2	17 N.W.
	Quarry in Hutton Combe	......	
Banwell	Quarry on the hill south of the village, north-west of Banwell Castle	C_2	17 N.E.
Sandford	Quarry at the western end of Sandford Hill	......	
Rowberrow-to-Churchill traverse.	Two adjacent quarries on the main road, west of Dolebury Camp ...	C_2	18 N.W.
Burrington Combe. .	(See above, p. 344)	C_1–C_2	
Blagdon	Quarry on the west side of the road, south of village...............	C_2	18 N.E.

South side.

Bleadon	Two quarries at Purn Corner, west of Bleadon	C_1	16 S.E.
	Little Down Quarries (see above, p. 344)................................	C_2	
Wonderstone.........	Cutting on the road between Bleadon and Wonderstone	C_1	17 S.W.
	Old quarry at Wonderstone		
Loxton	Quarry on the hill north of the School................................	......	
Crook Peak	Exposure at the summit	C_2 (top)	

Locality.	*Description.*	*Horizon.*	*Sheet.*
Axbridge	Quarry near the road on the west side of Shute-Shelve Hill, north-west of Axbridge .... Quarry north of the Sanatorium, north-east of Axbridge	C_2	17 S.E.
North-east of Axbridge, north-west of Cheddar.	Two quarries and two disused quarries in the combe west of Callow Hill, on the road to Shipham	C_1–C_2	18 S.W.
North of Cheddar Gorge.	Old quarry west of Piney-Sleight Farm	......	18 S.W.
Cheddar section ...	In the ravine running from Long Wood to the Gorge; and in the Gorge, due west of this ravine...	C_2	18 S.W.
South-east of Charterhouse.	Quarry near Templedown Farm..	C_2 (top)	18 S.E.

B. Isolated mass south of Cheddar.

Nyland	Small quarry on the eastern side of Nyland Hill .... Excavations beside the road leading to Nyland Farm, east of the Farm.	C_2	27 S.W.

C. The North-Hill pericline.

South side.

West of Priddy ...	(1) Small quarry and excavations in Coxton-End Lane, about 600 yards west of Dale Farm .... (2) Old quarry about 500 yards west of (1) .... (3) Small quarry in a field, about 230 yards west, a little north, of (2)	....	27 N.E.
South of Priddy ...	Quarry in a copse on the west side of Pilton Drove	C_2 (?) or S_1 (?)	27 S.E.
North of Pen Hill...	Quarry and adjoining old quarry, south side of the road, a little west of Sideling Plantation	C_1	28 S.W.

Ground probably connected with the North-Hill pericline.

Draycott	Quarry and adjoining exposures, on the hill north-east of Draycott.	......	27 N.W.
Draycott to Priddy.	Old quarry on the south side of 'New Road'	C_2	27 N.E.

D. The Pen-Hill pericline.

East side.

Locality.	Description.	Horizon.	Sheet.
North of Binegar Station.	Old quarry on the railway, about 1050 yards from the station......	Upper C_2	28 S.E.
South of Binegar Station.	Quarry on the railway, 350 yards from the station	C_2	
	Old quarry beside the railway, at the bridge near Whitnell Farm...	C_1	
Binegar Bottom ...	Cutting on the tramway which crosses the road; and small quarry in a field, immediately west of the tramway	C_2	

E. The Beacon-Hill pericline.

North side.

Oakhill	Quarry by Limekiln Farm, north of the village	C_1–C_2	42 N.W.
Stoke Lane	In a ravine running northward to Cook's Wood. Small quarry on the west side, and quarry on the east side farther north	C_2	
Leigh-upon-Mendip.	Quarry east of the Vobster Road, north-east of the Church	Upper C_2	42 N.E.
North-east of Whatley.	Murder Combe Quarry	....	30 S.W.
Vallis Vale, near Frome.	Four quarries (see above, p. 345).		

Seminula-Zone.

Where best exposed in the Mendip area:—

(*a*) The Cheddar section.

The fine section in the Cheddar Gorge includes the whole of the *Seminula*-Zone, and affords the best display of this zone to be found in the Mendips. S_1 is exposed, in the western part of the ravine which branches off the Gorge and runs northward to Long Wood, and all down the Gorge as far as the large quarry; in this quarry, the top of the subzone is very well seen. S_2 is not so well exposed; but the lower part of the Gorge, between the large quarry and a disused quarry immediately south of the Cliff Hotel, affords a nearly-continuous section.

A fairly-complete duplicate section can be examined in the upper reach of the Gorge, ascending from the mouth of the Long-Wood ravine.

(*b*) The Burrington section.[1]

Includes the whole zone, but the exposure is somewhat incomplete.

(*c*) Binegar and Gurney Slade.

S_1 is well seen in Binegar Quarry; and also in an extensive quarry, close to Moor's Farm, on the west side of the road, north of Gurney Slade.

(*d*) Holwell.

S_1 is finely displayed in the three quarries on the western side of the valley, and in the large disused quarry a little farther west.

List of Exposures in the Mendip Area.

A. The Black-Down pericline.

North side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Hutton	Quarry on the north-western border of Hutton Wood, south-west of the church	S_1	17 N.W.
Burrington Combe	(See below, footnote)	S_1, S_2	18 N.W.
South-west of Compton Martin.	Old quarry by Whitegate Lodge, at the head of Compton Combe.	......	18 S.E.
South of Compton Martin.	Butt's Quarry, west of Harptree-Hill Farm	top of S_2	19 S.W.
	Quarry on the east side of Wells road, near the south-eastern corner of Upper Harptree Wood	top of S_1	19 S.W.

South side.

Crook Peak	Quarry beside the road, south side of Crook Peak	S_1	17 S.W.
	Exposures on the southern flanks of Crook Peak	S_1	17 S.W.
	Quarry at Denny's Hole, near Dunnett-Head Farm	S_1	17 S.E.
Cross	Quarry near the reservoir, north of the main road	S_1	17 S.E.
Axbridge	Old quarries on the south side of Shute-Shelve Hill, near the railway, west of the station	S_1	17 S.E.
North of Cheddar	Quarry and adjoining section in Batt's Combe	S_1	18 S.W.
Cheddar Gorge	(See above, p. 347)	S_1, S_2	18 S.W. & 27 N.W.

[1] See Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. 1 (1905) pp. 36–37.

B. The North-Hill pericline.

North side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Green Down, west of Chewton Mendip.	Quarry near Lily-Combe Farm ...	top of S_2	28 N.W.
Chewton Mendip ...	Quarry in Willet's Lane, north-west of Chewton Priory	top of S_2	28 N.E.
East End, south of Chewton Mendip.	Quarry by the road, at the end of Manning's Lane, east of East End	......	28 N.E.

South side.

Between Priddy and Draycott.	Old quarry on the south side of 'New Road,' south-west of Bristol-Plain Farm	......	27 N.E.

C. The Pen-Hill pericline.

South side.

Milton Hill, north-west of Wells.	Milton Quarry, and quarry on the southern edge of Under Wood .	S_1	41 N.W.
Stoberry Warren, north of Wells.	Two adjacent quarries, at the northern end of Beryl Lane ...	Upper S_1 & Lower S_2	41 N.W.

East side.

Binegar Bottom ...	Discontinuous section, terminating in an old quarry	S_1	28 S.E.
Gurney Slade	Binegar Quarry; an extensive disused quarry on the east side of the road to Emborough; and a quarry beside the Emborough road, near Moor's Farm, north of Gurney Slade	S_1	28 S.E.
	Old quarry south-east of Binegar Quarry; and hillside section east of this old quarry............	S_2	28 S.E.

Complicated ground, probably connected with the Pen-Hill pericline.

South-west of Emborough.	Quarry in the wood termed 'Quar Tyning,' on the west side of the Wells road	top of S_2	28 S.E.
South of Emborough.	Exposures in a ravine, south-east of Lechmere Water, and west of Emborough Quarry............	......	28 S.E.

Probable westward extension of the Pen-Hill pericline.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Ebbor Rocks, south of Priddy.	Exposures throughout the gorge.	S_1	27 S.E.
	Old quarries about 1 mile north-west of the mouth of the gorge	Upper S_1 & Lower S_2	27 S.E.
North of Westbury.	Quarry on the hill, near Foxhill's Wood	......	27 S.E.

D. The Beacon-Hill pericline.

North side.

Between Oakhill and Stoke Lane.	Quarry in a field, immediately east of Batch Farm	Upper S_1	42 N.W.
	Cutting, in the lane through Limekiln Wood, north-east of Batch Farm	S_2	42 N.W.
Vallis Vale, near Frome.	The northern end of the vale; old quarry on the east side, and quarry on the west side	Lower S_1	30 S.W.

South side.

Holwell	Three quarries on the west side of the valley; and three disused quarries farther west	S_1	42 N.E.

E. Isolated masses north of the main outcrop.

South of East Harptree.

Near Morgan's Cottages.	Old quarry in a field, west of Morgan's Lane	......	19 S.W.

The Upper Vobster mass.

Upper Vobster	Vobster Quarry	Upper S & Lower S_2	29 S.E.

F. Isolated masses south of the main outcrop.

The Tor-Hill anticlinal.

Tor Hill, Wells	Torhill Quarry	Upper S_1	41 N.W.

The Dulcote-Hill mass (south of Dinder).

Locality.	*Description.*	*Horizon.*	*Sheet.*
Dulcote Hill	Dulcotehill Quarry and Dulcote Quarry	......	41 S.W.
Church Hill	Quarry on the road, a little west of Churchill House	......	41 S.W.
Paradise Hill.........	Quarry on the road, at the point where a lane branches off to Dungeon Farm.....................	......	41 S.E.

Mass south-east of Croscombe.

North of Old Wells Road	Old quarry on the south side of Titwell Wood	......	41 S.E.

Dibunophyllum-Zone.

Where best exposed in the Mendip area :—

(*a*) Green Down, west of Chewton Mendip.

A quarry near Lily-Combe Farm : base of D_1 well exposed.

(*b*) Emborough.

The old quarry, in the cutting leading to Emborough Quarry : Upper D_2 finely displayed.

(*c*) Gurney Slade.

A quarry on the north side of Gurneyslade Bottom : Lower D_1 well exposed.

(*d*) Between Oakhill and Stoke Lane.

The quarry in Limekiln Wood: part of D_1 very finely exposed.

(*e*) North of Stoke Lane.

A quarry beside Bector Lane, and a quarry in Cook's Wood : D_2 well seen.

List of Exposures in the Mendip Area.

A. The Black-Down pericline.

North side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Burrington Combe..	Quarry at the northern end of the section	base of D_1	18 N.W.
Ubley	Quarry at the eastern end of Ubley Wood, south of the village	D_2	18 N.E.
Compton Martin ...	Quarry at the mouth of Compton Combe	......	19 S.W.
	Butt's Quarry, west of Harptree-Hill Farm............................	base of D_1	19 S.W.
	Two old quarries, on either side of the road, at Wells-Way Inn .	D_1	19 S.W.

South side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Cheddar	Old quarry in Batt's Lane, south of Warren Hill	D_1	27 N.W.
	Cheddar Gorge: an old quarry beside the road, about 200 yards below the Cliff Hotel	Lower D_1	27 N.W.

B. The North-Hill pericline.

North side.

Green Down, west of Chewton Mendip.	Quarry near Lily-Combe Farm ...	base of D_1	28 N.W.
Chewton Mendip ...	Quarry in Willet's Lane, north-west of Chewton Priory	base of D_1	28 N.E.

South-east side.

Emborough	Exposures in a field, in the angle between Redhill Lane and the Wells road, south-west of Emborough	Upper D_2	28 S.E.

C. The Pen-Hill pericline.

East side.

Gurney Slade	Quarry on the north side of Gurneyslade Bottom	Lower D_1	28 S.E.
	Quarry, and old quarry, on the south side of Gurneyslade Bottom	Upper D_1	28 S.E.

Complicated ground, probably connected with the Pen-Hill pericline.

Emborough	Emborough Quarry, south of the Fuller's Earth & Ochre Works.	Lower D_1	28 S.E.
	Old quarry in the tramway-cutting, north of Emborough Quarry ...	Upper D_2	28 S.E.

Probable westward extension of the Pen-Hill pericline.

West of Ebbor Rocks, south of Priddy.	Exposures on the north-eastern slopes of the Ebbor Valley, bordering the Millstone Grit ...	Upper D_2	27 S.E.

D. The Beacon-Hill pericline.

North side.

Locality.	*Description.*	*Horizon.*	*Sheet.*
Between Oakhill and Stoke Lane.	Quarry in Limekiln Wood, north-west of Batch Farm	D_1	29 S.W.
North of Stoke Lane.	Old quarry near Moon's - Hill Farm, western edge of Cook's Wood	D_2	29 S.W.
	Quarry in Cook's Wood	D_2	29 S.W.
	Quarry on the east side of Bector Lane, east of Cook's Wood	D_2	29 S.W.
Mells	Mells Quarries (two)	D_1	30 S.W.

South side.

Leighton	Quarry in a field, north-west of the hamlet	D_1	42 S.E.

E. Isolated mass north of the main outcrop.

The Upper Vobster mass.

Upper Vobster	Old quarry opposite the siding on the mineral railway, south of Vobster Quarry	D_1	29 S.E.

V. Correlation of the Mendip and Bristol Areas.

The correlation of the palæontological sequence in the Mendip and Bristol areas is treated somewhat fully in my paper on the Burrington-Combe section,[1] but a detailed examination of the Mendips has since shown that the comparison there instituted, which was based solely on a knowledge of the Burrington section, requires considerable emendation.

In view of the close general similarity of the faunal sequence in the Mendips with that observed in the Bristol area, the following notes are confined almost entirely to the points of difference.

The *Cleistopora*-Zone.

A separation of the lowest portion of the Avonian as a distinct zone, namely, the *Modiola*-Zone, is less justifiable in the Mendips than in the Bristol area. For, while this part of the sequence is certainly characterized by the abundance of ostracods and the

[1] Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. 1, 1905 (issued for 1904) pp. 14–41.

common occurrence of Modioliform lamellibranchs,[1] its brachiopod-fauna, which includes some prolific forms, has not yielded any characteristic forms that could justify a separation from the Lower *Cleistopora*-Zone. In the Mendip area, therefore, the lowest beds of the sequence, which, in part, represent a particular phase of sedimentation, are grouped with the *Cleistopora*-Zone, and distinguished as a '*Modiola*-phase.'[2]

Horizon α cannot be distinguished in the Mendip sequence. The palæontological characters which, in the Bristol area, link Horizon α with the *Cleistopora*-Zone and distinguish it from the *Modiola*-Zone, are possessed by the *Modiola*-phase in the Mendip area.

So far as my own observations are concerned, *Cleistopora* aff. *geometrica* is a somewhat unsatisfactory zonal index in the Mendips. This fossil has, however, one advantage, namely, that it has never been recorded outside its own zone; on the other hand, it is either absent or very rare in K_1, and is apparently never common in K_2. *Camarotœchia mitcheldeanensis* would be a good zonal index in the Mendips; it is very abundant in K_1, abundant in K_2, and common at Horizon β, while apparently never common at any higher level. However, with the above comment, it is perhaps better for the present to retain *Cleistopora* as an index-fossil in the Mendip area, in view of the almost-complete identity of the zonal assemblage in the Mendip and Bristol areas; for, in the Bristol area, *Cleistopora* is often abundant in K_2, while *Camarotœchia mitcheldeanensis* persists abundantly throughout the Lower *Zaphrentis*-Zone.[3]

The characters of the *bassus*- and *octoplicata*-subzones in the Mendips are essentially those of the same subzones in the Bristol area, but the following minor points of difference are noticeable:—

(1) The earlier entrance of *Spirifer* aff. *clathratus*, *Reticularia* cf. *reticulata*, and *Rhipidomella* aff. *Michelini* in the Mendip sequence; and the greater abundance of *Spirifer* aff. *clathratus* throughout this zone in the Mendips.

(2) The comparative scarcity of *Leptæna analoga* throughout this zone in the Mendip area.

(3) The occurrence of *Athyris* (*Actinoconchus*) cf. *lamellosa* in the *octoplicata*-subzone of the Mendips.

The *Zaphrentis*-Zone.

An important feature of the sequence in the Mendips, when compared with that in the Bristol area, is the great expansion in thickness of this zone. The total thickness of the *Zaphrentis*-Zone, estimated in the Burrington section, is about 800 feet, while that of the same zone in the Avon section is rather less than 400 feet.

[1] So far as I am aware, no specimen of *Modiola* has yet been determined from the Mendip area.

[2] Since the lamellibranchs in these lowest beds of the Mendip sequence are, as yet, very imperfectly known, I retain the term '*Modiola*-phase,' so as to secure uniformity with the zonal scheme in the Bristol area.

[3] In the Mitcheldean district (Gloucestershire), *Camarotœchia mitcheldeanensis* persists abundantly up to Horizon γ.

Corresponding to the *clathratus*- and *resupinata*-subzones of the Bristol area, we have the *clathratus*- and *cornucopiæ*-subzones of the Mendip sequence. The reason for adopting *Zaphrentis* aff. *cornucopiæ* as a subzonal index in the Mendips, in preference to *Schizophoria* aff. *resupinata*, is as follows:—*Schizophoria* aff. *resupinata* occurs somewhat sparingly below Horizon γ, and attains its maximum immediately above that horizon, that is, in the base of *Syringothyris*-Zone: whereas *Zaphrentis* aff. *cornucopiæ* is very common throughout the upper half of the *Zaphrentis*-Zone, and attains its greatest abundance below Horizon γ: in fact, the extent of the upper subzone is well defined by the range of the latter fossil, in its typical form.

The differences between the Mendip and Bristol areas, in the range and relative abundance of various fossils throughout this zone, can be studied by comparing my range-diagrams (Pls. XXXIV & XXXV) with those of Dr. A. Vaughan.[1] The important points of difference may be summarized by stating that, in the Mendip area, there is a relative acceleration of the coral-fauna on the brachiopod-fauna, in this part of the sequence. This relative acceleration is exemplified in the following notes.

In the Bristol area:—

Michelinia is rare in Z_1.

The maximum of *Syringothyris* aff. *cuspidata*, mut. C lies in Z_2, that is, below the maximum of *Caninia*.

Schizophora aff. *resupinata* is most abundant at the base of Z_2, that is, below the maxima of *Caninia* and *Zaphrentis*.

Spirifer aff. *clathratus* and var. are uncommon at Horizon γ, which level contains the maxima of *Caninia* and *Zaphrentis*.

In the Mendip area:—

Michelinia is abundant in the lower part of Z_1.

The maximum of *Syringothyris* aff. *cuspidata*, mut. C occurs in the *Syringothyris*-Zone, that is, above the maximum of *Caninia*.

Schizophoria aff. *resupinata* attains its maximum abundance immediately above Horizon γ, that is, above the maxima of *Caninia* and *Zaphrentis*.

Spirifer aff. *clathratus* and var. are still abundant at Horizon γ; this level contains the maximum of *Caninia*, but the maximum of *Zaphrentis* lies somewhat lower.

The very strong definition of Horizon γ, by the great abundance of *Caninia cylindrica*, is a noticeable feature of the Mendip sequence. (Compare the Clevedon district[2] and the Backwell-Wrington mass[3] in the Bristol area.)

The *Syringothyris*-Zone.

The most important difference between the Mendip and Bristol areas lies in the development of this part of the sequence.

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) pls. xxviii & xxix (facing pp. 244 & 246).
[2] *Ibid.* p. 228. [3] *Ibid.* p. 240.

In the Bristol area, shallow-water conditions prevailed during the greater part of *Syringothyris*-time, as evidenced by the extensive development of pure oolite, shales, and dolomites in the *Syringothyris*-Zone. The consequent interruption of the faunal progression in this part of the Avonian sequence forms a prominent feature in the Bristol development. Additional evidence of physiographical disturbance is afforded by the occurrence of contemporaneous igneous rocks at the base of the zone (Horizon γ) at several localities in the Bristol area.

The Mendip area, on the other hand, remained comparatively free from disturbance,[1] and shows little or no interruption of the faunal sequence. The *Syringothyris*-Zone, which is considerably thicker than the equivalent part of the Bristol sequence, consists entirely[2] of fossiliferous limestone, and possesses a well-characterized faunal assemblage, in which the decline of the Clevedonian fauna, and the genesis of the Kidwellian, is well displayed. The lowest portion of the zone is slightly dolomitized.

The '*Bellerophon*-Beds,' in the *Syringothyris*-Zone of Failand[3] and Tickenham,[4] in the Bristol area, exhibit the palæontological characters of the Upper *Syringothyris*-Zone of the Mendip area, and indicate a temporary establishment of the Mendip facies in that part of the Bristol area.

The Weston-super-Mare district,[5] which lies between the Bristol and Mendip areas, exhibits an intermediate type of development in the *Syringothyris*-Zone. The lowest part of the zone is appreciably dolomitized, and is succeeded by a thick band of pure oolite, but the upper and main part of the zone exhibits a continuously-fossiliferous sequence, similar to that of the Mendip area.

Since this zone, in the Mendip area, contains an abundant coral- and brachiopod-fauna which is but feebly represented in the equivalent part of the Bristol sequence, a detailed comparison of palæontological features would be superfluous. The following points, however, are worthy of special notice :—

(1) *Syringothyris* aff. *laminosa* is an important fossil in the *laminosa*-subzone of the Bristol area (= Lower *Syringothyris*-Zone of the Mendips), but is never common in this zone in the Mendip area, where it attains its maximum in the Upper *Zaphrentis*-Zone.

(2) *Syringothyris* aff. *cuspidata*, mut. C attains its maximum in this zone in the Mendip area, but in the uppermost part of the *Zaphrentis*-Zone in the Bristol area.

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[1] Igneous rocks associated with the Carboniferous Limestone have been found at one locality only in the Mendip area, namely at Uphill, in the westernmost part of the area. The igneous rock is there associated with Upper *Zaphrentis*-beds, probably very near Horizon γ, but there is no direct evidence to establish its contemporaneity. See C. Lloyd Morgan & S. H. Reynolds, Quart. Journ. Geol. Soc. vol. lx (1904) pp. 146, 150.

[2] An occasional, very local development of unfossiliferous oolites is found, as, for example, at Hutton.

[3] A. Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 217.

[4] A. Vaughan, *ibid.* p. 231.

[5] See T. F. Sibly, *ibid.* pp. 548–61.

(3) *Athyris* cf. *expansa*, which is an important fossil in this zone in the Mendips, is not known in the Bristol area.
(4) *Caninia cylindrica* attains its second maximum in the upper part of this zone in the Mendips, but in the Lower *Seminula*-Zone in the Bristol area. This is another example (see above, p. 355) of the relative acceleration of certain coral-groups on the brachiopod-progression in the Mendips as compared with the Bristol area.

The *Seminula*-Zone.

The differentiation of this zone into a lower subzone (S_1) in which the *Seminula*-fauna contains certain survivors of the *Syringothyris*-fauna, and an upper subzone (S_2) possessing a limited but essentially-Kidwellian fauna, is a well-marked feature in the Mendips, as in the Bristol area. The only noticeable differences between the two areas are to be found in the characters of S_1; and part of the difference between the Mendip and Bristol development of S_1 is undoubtedly due to the fact, that the lowest portion of this subzone consists of fossiliferous limestones in the Mendips, and of relatively-unproductive shales and dolomites in the Bristol area. The most important points of difference are the following:—

(1) In the Bristol area, *Seminula* becomes abundant before giganteid *Producti* are common, and is very prolific in S_1. In the Mendips, on the other hand, giganteid *Producti* are abundant throughout S_1, whereas *Seminula* only becomes abundant in the upper part of that subzone.
(2) *Athyris* cf. *expansa* and *A.* cf. *glabristria*, mut. S_1, two fossils which are important in S_1 of the Mendip sequence, are not met with in the Bristol area.
(3) The base of S_1 in the Mendips contains, locally, a rich faunal assemblage,[1] which is especially characterized by the abundance of *Carcinophyllum mendipense*, *Camarophoria isorhyncha*, *Spirifer* cf. *furcatus*, and *Athyris* cf. *glabristria*, mut. S_1. No similar development is known in the Bristol area.
(4) *Caninia cylindrica* attains its second maximum in S_1 in the Bristol area. In the Mendip area, *Caninia cylindrica* attains its second maximum in the Upper *Syringothyris*-Zone, and is not common in S_1.

The *Dibunophyllum*-Zone.

The development of shales in this part of the Mendip sequence is small, when compared with that in the *Dibunophyllum*-Zone of the Bristol area.

The $\theta\phi$ and *Lonsdalia*-subzones.

The faunal characters of these subzones in the Mendip area are more nearly identical with those of the same subzones in the Bristol

[1] It would seem that this fauna had a very local distribution. For example, the base of the *Seminula*-Zone is exposed in both the Cheddar and Burrington sections; but, whereas the former section shows a fine development of this fauna, I have failed to discover any trace of a similar horizon at Burrington. The Milton-Road Quarries, in the Weston-super-Mare district, show a development precisely similar to that which is noted at Cheddar.

area, than is the case with any other part of the sequence. Consequently, very few points call for special mention.

(*a*) The common occurrence of *Athyris* cf. *expansa* in the $\theta\phi$-subzone of the Mendip sequence constitutes a noticeable difference.

(*b*) Distinctive features of the *Lonsdalia*-subzone, in the Mendip area, as compared with the Bristol area, are :—

(1) The great abundance of a well-defined member of the group of giganteid *Producti*, namely, *Productus* ϕ.

(2) The great abundance of *Productus concinnus*, mut. D_2 in the uppermost beds.

The *Lonsdalia*-subzone in the Mendips has not yielded so prolific a coral-fauna as that found in D_2 of the Bristol area, but this is, doubtless, due to the small number and limited extent of the exposures.

Horizon ϵ.[1]

So far as I am aware, this horizon is not exposed in the Mendip area. Consequently, we are for the present ignorant of an important matter, namely, the exact position which this horizon occupies with regard to the base of the 'Millstone Grit' in the Mendip sequence.

Note on the Separation of the *Syringothyris*-Zone and the *Seminula*-Zone in the Mendip Area.

In the sequence typical of the Bristol area, the palæontological break in the middle of the Avonian renders the separation of the *Syringothyris*- and *Seminula*-Zones an easy matter, for the uppermost part of C consists of unproductive shales and dolomites, and, when fossiliferous beds are again met with, they are found to contain a typical *Seminula*-fauna. In the Mendip area, however, where the upper part of C and the lower part of S form a continuously-fossiliferous sequence, and the change from a typical *Syringothyris*-fauna to a typical *Seminula*-fauna is gradual, the separation of the two zones requires special definition.

There is no well-defined horizon of faunal overlap between C and S in the Mendip sequence. Giganteid *Producti*, including *Productus* aff. *Cora*, mut. C and *Pr.* θ, occur commonly throughout the upper part of C, and *Seminula* aff. *ficoides* enters sparingly in the uppermost beds. These facts do not, however, justify a separation of the uppermost part of C (which contains *Syringothyris* aff. *cuspidata*, mut. C, but no *Lithostrotion Martini*),[2] as a definite horizon of overlap. Again, the subzone S_1 contains a predominant *Seminula*-fauna associated with certain survivors of the *Syringothyris*-fauna, but

[1] See A. Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 262.

[2] *Lithostrotion* cf. *irregulare* occurs in the uppermost beds of C, but has not been found in S_1.

never contains *Syringothyris* aff. *cuspidata*, and would constitute a very broad and ill-defined 'horizon' of faunal overlap.

In the absence of any satisfactory horizon of overlap, it becomes necessary to fix some arbitrary but satisfactory line of separation. *Seminula ficoides* is not common in the lowest part of S, and is, therefore, of little value for determining the base of that zone. But *Lithostrotion Martini*, as a dominant form, is characteristic of the whole *Seminula*-Zone, while it has never been found in association with *Syringothyris* aff. *cuspidata*. The base of the *Seminula*-Zone is, therefore, best defined by the horizon of first occurrence of *Lithostrotion Martini*.

It may be mentioned again here, that the base of the *Seminula*-Zone (as defined by the first occurrence of *Lithostrotion Martini*) is sometimes marked, in the Mendip area, by the great abundance of that fossil, which is associated with a highly-characteristic fauna. The characteristic members of this fauna are *Carcinophyllum mendipense*, *Camarophoria isorhyncha*, *Spirifer* cf. *furcatus*, and *Athyris* cf. *glabristria*, mut. S_1. Unfortunately, this faunal assemblage is, apparently, localized in its distribution.[1]

Note on the Distinctness of the Clevedonian and Kidwellian Faunas in the Mendip Sequence.

The following genera of corals are confined to the Clevedonian :—

Cleistopora, Michelinia, Zaphrentis, Amplexus.[2]

The following brachiopod-groups are confined to the Clevedonian :—

Athyris cf. *lamellosa.*
Reticularia cf. *reticulata.*[3]
Spirifer aff. *clathratus.*
Spiriferina cf. *octoplicata.*
Syringothyris aff. *cuspidata.*
Syringothyris aff. *laminosa.*
Eumetria aff. *carbonaria.*
Camarotœchia mitcheldeanensis.
Leptæna analoga.
Schizophoria aff. *resupinata.*
Productus bassus.
Productus cf. *Martini.*
Chonetes '*Buchiana.*'
Chonetes cf. *crassistria.*
Chonetes cf. *hardrensis.*

The following coral-groups are confined to the Kidwellian :—

Alveolites septosa.
Lithostrotion.[4]
Cyathophyllum Murchisoni (type).
The great group of the Clisiophyllids[4] (including *Lonsdalia*).

The following brachiopod-groups are confined to the Kidwellian :—

Productus scabriculus.
Athyris cf. *planosulcata.*

The great group of the giganteid *Producti* is essentially charac-

[1] See footnote, p. 357.
[2] Possibly ranges into the base of the Kidwellian.
[3] Occurs very rarely in the base of the Kidwellian.
[4] Very few early forms occur in C.

teristic of the Kidwellian; but early forms of *Productus* aff. *Cora* occur very rarely in Z, and commonly in C.

The following coral-groups pass up from the Clevedonian into the Kidwellian :—

Syringopora. The sole essentially-Clevedonian form is *Syringopora* θ. *S.* cf. *reticulata* characterizes the uppermost Clevedonian, but persists into the base of the Kidwellian. The types represented by *S.* cf. *distans*, *S.* cf. *geniculata*, and *S.* cf. *ramulosa* are essentially Kidwellian, although *S.* cf. *distans* occurs rarely in C.

Caninia cylindrica is essentially an Upper Clevedonian form, which persists into the base of the Kidwellian.

Cyathophyllum ϕ characterizes the uppermost part of the Clevedonian and the base of the Kidwellian.

Campophyllum occurs commonly in the uppermost part of the Clevedonian and the Upper Kidwellian.

The following brachiopod-groups pass up from the Clevedonian into the Kidwellian :—

Productus cf. *semireticulatus.*

Athyris cf. *glabristria.* This group ranges throughout the greater part of the Clevedonian, and persists into the Lower Kidwellian.

Athyris cf. *expansa* constitutes a distinct link between the uppermost Clevedonian and the Kidwellian.

Orthothetes aff. *crenistria* is a very important link; but, whereas it is enormously abundant throughout the Clevedonian, it is rare above the lowest part of the Kidwellian.

Rhipidomella aff. *Michelini* is very abundant throughout the main part of the Clevedonian, and persists into the base of the Kidwellian.

Chonetes cf. *papilionacea* constitutes an important link between the Upper Clevedonian and the Lower Kidwellian.

Seminula is an essentially-Kidwellian genus; but *S. ambigua* is common in the upper part of C, and *S.* aff. *ficoides* occurs rarely in the uppermost beds of the Clevedonian.

VI. Summary.

(1) The faunal sequence in the Avonian (Carboniferous Limestone) of the Mendip area is essentially similar to that in the Bristol area.

(2) The separation of a lower division, the Clevedonian, from an upper division, the Kidwellian, with the line of separation drawn at the top of the *Syringothyris*-Zone, is well-defined, and fully justified by the distinctness of the lower and upper faunas.

(3) The most important features of the Mendip sequence, when compared with the sequence in the Bristol area, are as follows :—

(*a*) The great expansion in thickness of the *Zaphrentis*- and *Syringothyris*-Zones.

(*b*) A relative acceleration of the coral-fauna on the brachiopod-fauna, exhibited in the *Zaphrentis*-Zone.

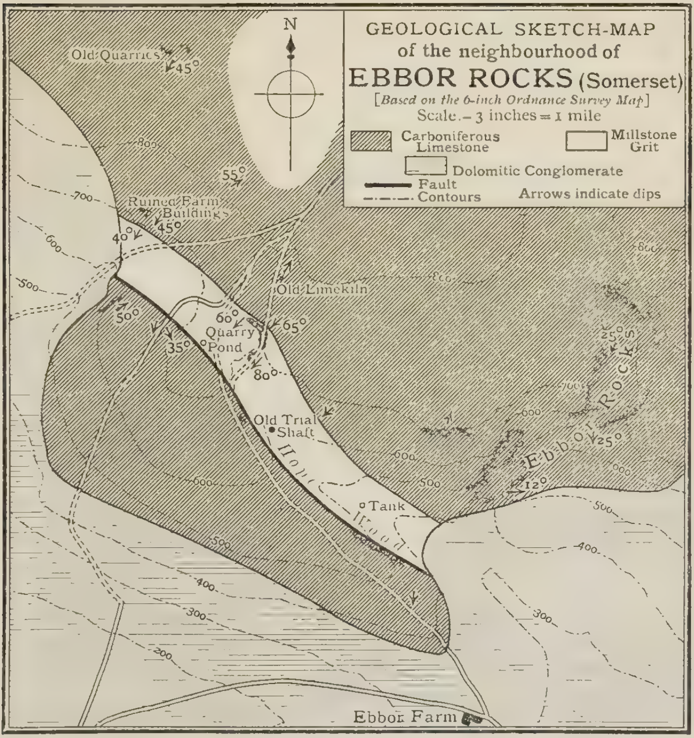
(*c*) The continuously-fossiliferous sequence which extends from the top of the *Zaphrentis*-Zone to the base of the *Seminula*-Zone; this sequence exhibits an abundant and characteristic coral- and brachiopod-fauna, and is well-defined as the *Syringothyris*-Zone.

VII. Notes on the Geology of the Ebbor-Rocks District, near Wells.

From the mouth of Ebbor Rocks, a picturesque little valley runs, in a north-westerly direction, up into the hills. The geological features of the immediate neighbourhood of this valley have received considerable attention.

According to the Geological Survey-memoir,[1] there is a puzzling fault-complex in this locality, which may be briefly described as follows. Millstone Grit occurs at the head of the valley, succeeding conformably the Carboniferous Limestone on the north; with the former are associated carbonaceous shales. In the valley itself

Fig. 1.



occur Old Red Sandstone and 'Lower Limestone Shales,' which are succeeded conformably by the Carboniferous Limestone on the north, but are faulted against Carboniferous Limestone on the south, and against Millstone Grit on the west.

[1] 'The Geology of East Somerset & the Bristol Coalfields' 1876, pp. 16, 18, 30; see also a paper by H. W. Bristow & H. B. Woodward, in Geol. Mag. vol. viii (1871) p. 500.

In 1889, however, Prof. C. Lloyd Morgan, who made a careful examination of the ground, came to the conclusion[1] that the insertion, on the Geological Survey-map, of Old Red Sandstone and 'Lower Limestone Shales' was incorrect, and that Millstone Grit, with associated carbonaceous shales, extends right down the valley.

In the hope of throwing some further light on the geology of this interesting locality, I have devoted a considerable amount of time to a very careful examination of the ground; and the result of my investigation has been to confirm the conclusions arrived at by Prof. Lloyd Morgan. During the course of my work, however, several important stratigraphical features have become apparent, and these, I think, warrant some further description of the neighbourhood.

The description falls naturally into three parts.

(i) The Millstone Grit and associated shales, etc.

The lowest beds of the Millstone-Grit Series are now very well exposed in a quarry, recently opened, at the head of the valley (see map, fig. 1, p. 361). This quarry lies on the south side of a wall, in the course of a footpath which affords a short cut from the Priddy-to-Easton track to the track leading down to Ebbor Farm. The lowest beds seen in the quarry are pinkish-white quartzites with red ferruginous specks; these beds reappear on the north side of the wall, and there lie only 20 yards from the nearest limestone-exposure. Grey and red shales become interbedded with the upper beds of the grit, and predominate in the upper part of the quarry. The general dip of 60° to 65° southward, and the strike of about north 40° west, indicate conformity with the underlying limestones, although in the upper part of the quarry the beds are somewhat disturbed. I have found no fossils in these beds; but Mr. H. E. Balch possesses a large piece of *Sigillaria*, obtained from the grit, and he informs me that such specimens are occasionally found by the quarrymen.

About 100 yards south of the quarry, well-bedded greyish sandstones, dipping southward at 80° and striking north 42° west, are exposed in a small working.

In a cattle-pond lying about 180 yards west 20° south of the quarry, grey and reddish shales are exposed. Only 25 yards south of this pond, hard grey limestones, much veined with calcite, are seen *in situ*. The greatest width of the outcrop of the grit-shale series probably never exceeds 200 yards.

An old pit, mentioned in the Geological Survey-memoir,[2] lies about 100 yards west of the quarry. Prof. Lloyd Morgan found fragments of coal in the spoil-heap of this pit; and Mr. Balch informs me that a coal-seam, about 1 foot thick, was proved.

North-west of the quarry, the hard quartzites are again exposed, south of the ruined farm-buildings. They dip southward at about

[1] Proc. Bristol Nat. Soc. n. s. vol. vi (1890–91) p. 173.

[2] 'The Geology of East Somerset & the Bristol Coalfields' 1876, p. 30.

45°, and strike west 28° north. They lie 60 or 70 yards south-west of limestones, which have precisely the same dip. Beyond this point, the north-westward extension of the grit is concealed by the Dolomitic Conglomerate.

Down the valley, almost due south of the quarry, lies a second old pit, worked in 1871. According to the Survey-memoir, this pit was sunk through 'Lower Limestone Shales'; but, as Prof. Lloyd Morgan stated, the shales in the spoil-heap yield no fossils, and have the lithological character of Coal-Measure shales.

Still farther down the valley, on the north-eastern slopes, are several exposures of precisely-similar shales, and other exposures of hard, sandy shales; the southernmost of these exposures lies quite 200 yards beyond the water-tank. Wherever the dip can be made out, these shales are seen to dip southward. Grit is exposed, *in situ*, on the slopes almost directly north of the tank, and loose blocks can be found dispersedly all down the north-eastern slope of the valley.

On the south-western slope of the valley, in Hope Wood, the shales are exposed at various points, to within a very short distance of the limestone-bluff on the southern edge of the wood.

(ii) The Carboniferous Limestone north and east of the Valley.

(*a*) The Upper *Dibunophyllum*-Zone.

Wherever the limestone immediately north of the Millstone Grit is exposed, and fossils can be found, the palæontological characters clearly indicate D_2; and, although the actual junction of the limestone and the grit is nowhere exposed, there is never any suggestion of unconformity.

The best exposure is that north of the quarry. Here, the highest limestones seen, which lie 20 yards (measured along the direction of dip) from the lowest exposure of grit, contain much lenticular chert, but have yielded no fossils. Fifty yards from the grit, however, the limestone still has the same dip, and certain beds are highly fossiliferous. *Productus* ϕ and *Pr. punctato-fimbriatus* are very abundant, and *Pr.* sp. (convergent with *Pr. margaritaceus*) is not uncommon; these fossiliferous beds lie about 130 feet vertically below the lowest grit of the quarry.

North-westward, near the ruined farm-buildings, the limestone 60 or 70 yards from the grit (the dip here is less than at the first exposure) contains abundant *Productus* ϕ.

South-eastward are several small exposures of limestone, on the north-eastern slope of the valley, all of which must lie very near the Millstone Grit. In most cases the dip of the beds is obscure; but, in all instances where it can be made out, it is seen to be southward. Fossils are scarce, though I have obtained *Cyathophyllum* sp., *Lithostrotion Martini*, mut., *Athyris* cf. *expansa*, *Chonetes* aff. *comoides*, and *Productus* sp. convergent with *Pr. margaritaceus*.

In the easternmost exposures, however, which lie near the margin of Ebbor Wood, almost due north of the water-tank, certain beds are highly fossiliferous, and have yielded the following fossils:—*Productus concinnus*, mut. D_2 and *costatus*-like variants (very abundant), *Pr. hemisphericus*, mut., *Pr.* ϕ, *Pr. punctato-fimbriatus*, *Chonetes* aff. *comoides*, *Spirifer* cf. *bisulcatus* and *Rhipidomella* sp. According to the Geological Survey-memoir,[1] the beds in these last exposures must immediately overlie the 'Lower Limestone Shales' and dip northward; whereas they represent a high level in D_2, and are, in all probability, succeeded conformably by the Millstone Grit on the south, although it is impossible to determine their dip with certainty.

Farther eastward, the limestone bordering the Millstone Grit is concealed by Ebbor Wood, and the Dolomitic Conglomerate soon cuts off the outcrop of the Carboniferous rocks.

(*b*) The *Seminula*-Zone.

There is not sufficient evidence to determine accurately the relation of the *Seminula*-beds, which are exposed in Ebbor Rocks and elsewhere north of the valley, to the beds of the Upper *Dibunophyllum*-Zone. The former rocks are considerably disturbed; in all the most southerly exposures they have a northerly dip, and farther north they dip southward. If the beds turn completely over in a short distance, there may possibly be a sequence north of the quarry; there is not room, however, for a sequence, from the top of S_1 to the base of the Millstone Grit (about 900 feet), between the mouth of Ebbor Rocks, or the exposures on the hill north-west of that point, and the edge of the Millstone-Grit outcrop. The most probable explanation is a fault; but there is not evidence enough to trace the course or the limits of this fault with accuracy, and the matter must, therefore, be left open.

The exposures of the *Seminula*-beds are as follows:—

In Ebbor Rocks, the upper part of S_1 is displayed. The faunal assemblage, comprising *Lithostrotion Martini* (abundant), *Syringopora* cf. *reticulata*, *Productus* θ (abundant), *Pr.* aff. *Cora*, *Pr.* cf. *semireticulatus*, mut. S_1, *Seminula ficoides*, *Athyris* cf. *expansa*, *A.* cf. *planosulcata*, and *Chonetes* cf. *papilionacea*, leaves no doubt as to the horizon. In the lower part of the gorge, the prevalent dip is a low easterly one; in the upper part, separated from the lower by a wooded gap, the dip is about 25°, and varies from south to south-west. Here, then, is apparently a synclinal fold of some kind in the *Seminula*-beds.

High up on the north-eastern side of the valley, immediately north-west of the mouth of the gorge, *Seminula*-beds are exposed in a low cliff, and at several points in the fields; the precise horizon is uncertain. Here the beds have a low northerly dip. These exposures lie only about 150 yards from the nearest exposure of D_2.

Much farther north-westward, the exposures are scanty, but they afford further evidence of disturbance. Beside the footpath, about

[1] See the illustrative section, *op. cit.* fig. 2, p. 19.

160 yards above the quarry, is an old limekiln; here, in a small disused quarry and adjoining exposures, compact limestones, dipping northward, show abundant *Seminula ficoides* and *Productus* sp. Some 50 yards farther up the path, similar beds, with the same fossils, are again seen dipping northward. Limestones of this lithological character, and containing abundant *Seminula ficoides*, can be assigned to S_2 with certainty. North-west of these exposures, in two adjoining fields, is a considerable exposure showing hard black limestones, dipping north-eastward at 55°. Finally, still farther north-westward, are exposures on the site of two adjacent disused quarries. Here, as in the uppermost part of Ebbor Rocks, the beds dip south-westward; the dip is 45° and the strike west 33° north. The upper beds are compact black limestones, with abundant *Seminula ficoides*: the lower beds are dark reddish limestones, containing *Lithostrotion Martini* (very abundant), *Productus* θ (abundant), and *Athyris* cf. *expansa*. The horizon of this exposure is, therefore, Upper S_1 and Lower S_2.

(iii) The Carboniferous Limestone south and west of the Valley.

The north-eastern boundary of this mass of limestone marks the course of a great thrust-fault, with an upthrow of about 2000 feet, which has thrown *Zaphrentis*-beds and *Syringothyris*-beds obliquely against the shales of the Millstone-Grit Series, and reduced the outcrop of that series to a narrow strip, about 200 yards wide, running north-west and south-east.

The Upper *Zaphrentis*-beds are well exposed, near the north-western extremity of the mass, in the bluff which rises on the eastern side of the footpath leading from Lynchcombe Lane (Westbury) onto the hills toward Priddy. The beds here exposed are black crinoidal limestones, and contain a typical Z_2 fauna, comprising *Zaphrentis* aff. *cornucopiæ* (abundant), *Z.* aff. *Phillipsi*, *Caninia cylindrica*, *Michelinia* cf. *favosa*, *Spirifer* aff. *clathratus* (common), *Rhipidomella* aff. *Michelini*, *Orthothetes* aff. *crenistria*, and *Chonetes* cf. *hardrensis*; they dip north-westward at about 50°, their strike being N. 37° W. The prevalent dip of the beds throughout the mass is, however, southward. Z_2 is again exposed on either side of the Priddy-to-Easton lane, about 200 yards east of the bluff; here the dip is about 35°, southward.

There are several exposures near the south-eastern extremity of the mass, notably the limestone-scarp, facing north-eastward, on the southern edge of Hope Wood. Very near the south-eastern end, on the track leading down to Ebbor Farm, just above the lane, are some small limestone-exposures. The beds here contain *Zaphrentis* aff. *cornucopiæ*, mut. C, *Syringopora* cf. *distans*, *Productus* aff. *Cora* (?), *Spirifer* cf. *bisulcatus*, and *Rhipidomella* aff. *Michelini*. These beds, which dip southward, clearly belong to the *Syringothyris*-Zone, and are, doubtless, in sequence with the Upper *Zaphrentis*-beds.

The course of the fault can be traced with some accuracy, and the limestone-exposures bordering the fault are of interest. At several points, the limestone has been converted into a fine-grained white or pinkish marble. This is especially well seen in a working on the south-western slope of the valley, about 300 yards south, a few degrees west, of the quarry. At other points near the fault, the grey limestones are very compact in texture, and strongly veined with calcite.

To sum up, the geological features of this locality, as I read them, are as follows:—

(1) Millstone Grit, with associated shales and sandstones, extends uninterruptedly down the valley, the outcrop forming a narrow strip, about two-thirds of a mile long and 150 to 200 yards wide; on the north-west and on the south-east, its outcrop is terminated by the Dolomitic Conglomerate.

(2) Upper *Dibunophyllum*-beds lie conformably under the grit on the north-eastern side.

(3) The *Seminula*-beds, exposed farther north-eastward, in Ebbor Rocks and elsewhere, are considerably disturbed. Their relation to the *Dibunophyllum*-beds is uncertain, but is probably complicated by faulting.

(4) A great thrust-fault has brought up the Carboniferous Limestone on the south-west, throwing *Zaphrentis*-beds and *Syringothyris*-beds against the shales of the Millstone-Grit Series.

VIII. Notes on certain Corals and Brachiopods included in the Faunal Lists.

(i) CORALS.

Amplexus.

Amplexus cf. coralloides, Sow.

The specimens included here, which are all obtained from the Upper *Zaphrentis*-Zone, have the following characters:—Form: large and cylindrical. Septa short, stout, and practically equal in thickness throughout their length, being square-cut at the end. Fossula not very strongly developed.

Amplexus sp.

Specimens which occur commonly in the *Syringothyris*-Zone, near Whatley, have short, thickened, tapering septa. The fossula is well-developed. The form is large and cylindrical.

Zaphrentis (restricted), Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 269.

Zaphrentis aff. cornucopiæ, mut. C.

Compare *Zaphrentis* aff. *cornucopiæ* (Mich.), Edwards & Haime, Vaughan, *op. cit.* p. 271 & pl. xxii, figs. 3–3 *d*.

This mutation, which characterizes the *Syringothyris*-Zone in the Mendip area, differs from the typical Z_2 form, described and figured

by Dr. A. Vaughan, in the following characters:—(1) Larger, more widely-conical form; (2) more numerous septa (there are forty to forty-five primary septa); and (3) longer secondary septa, which project inwards well beyond the thickened wall.

Caninoid **Cyathophylla**. (Pl. XXXI, fig. 1.)

Compare:—*Caninia cylindrica* (Scouler), mut. γ, Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 273 & pl. xxiii, fig. 1.
Cyathophyllum ϕ, Vaughan, *ibid.* p. 274 & pl. xxiii, figs. 3–3 *b*.

In the *Syringothyris*-Zone of the Mendip area[1] occur some very interesting corals, the characters of which are intermediate between those of *Caninia cylindrica* and *Cyathophyllum* ϕ. Individual specimens exhibit considerable variation, and the following descriptive notes deal with the general characters. Pl. XXXI, fig. 1 illustrates a specimen in which the Caninoid characters are somewhat accentuated.

Form: large, cylindrical to cylindro-conical.

The tabulæ form broad, flat plates, a majority of which extend completely across within the inner wall; they bend downward outside the inner wall. The fossula forms a well-marked, parallel-sided, shallow groove. The primary septa run in along the face of a tabula, extending almost to the centre.

Horizontal section.—Primary septa, 65 to 80 in number. A minority only of the primary septa extend actually to the outer wall; but the peripheral, purely-vesicular area is narrow and inconstant, while both the outer wall and the vesicles show numerous septal projections.

The external area, radiated by both series of septa, is narrow.

The secondary septa project inwards for a short distance from the inner wall.

The septa are never strongly thickened, except in the immediate neighbourhood of the inner wall, nor do they show any special thickening near the fossula.

The fossula, occupied by a shortened primary septum, is indicated by an inward shift of the tabular intersections. The two primary septa bounding the fossula are practically parallel one to the other.

Interseptal vesicles, representing tabular intersections, are very few in the medial area, radiated by the primary septa.

Resemblances and differences.—The corals of this type resemble *Caninia cylindrica*, mut. γ in the nature of the tabulæ, and in the possession of a purely-vesicular peripheral area; but differ from the typical form of that coral in the thinness of the peripheral vesicular area, in the more numerous, slightly-thickened septa, and in the weaker development of the fossula.

Cyathophyllum ϕ closely resembles the forms under description in the character and the large number of the primary septa, and in the nature of the septal break. It differs, however, in the

[1] Nearly identical forms occur in the *Syringothyris*-Zone of the Weston-super-Mare district.

semivesicular nature of its tabulæ, in the absence of a purely-vesicular peripheral area, and, finally, in the greater width, and the more closely-vesicular nature, of the external area, radiated by both series of septa.

Campophyllids.

Campophyllum, Edwards & Haime.

See Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 276.

Campophyllum caninoides, sp. nov. (Pl. XXXI, figs. 2 *a* & 2 *b*.)

Form: cylindrical to cylindro-conical. Epitheca strongly rugose.

Horizontal section.—Outer wall strong, with its septal projections equal to the total number of septa. Outer and inner walls in contact at certain points, but otherwise separated by a vesicular area.

Vesicular area very variable in thickness, consisting of one or two, rarely three or more, rows of large vesicles; never continuously radiated by the septa, but frequently showing septal projections.

The primary septa, 45 to 55 in number, are thin, short, and all approximately equal in length; they stop short of the centre, leaving a wide, purely-tabulate area.

Secondary septa generally developed, forming very short projections from the inner wall.

The fossula is indicated by a slight inward shift of the tabular intersections at one point of the ring, and is marked by one or more shortened primary septa.

Vertical section.—Tabulæ well-spaced, continuous from side to side; flat throughout the central part, and bending sharply downward within the septal zone. Outermost zone narrow and variable, formed of one or two vertical rows of ascending vesicles.

Remarks.—This species occurs very abundantly in the Upper *Syringothyris*-Zone, in certain parts of the Mendip area.

The uniformly-developed, short septa, the very slight fossular depression, and the strong outer wall, characterize the form under description as a *Campophyllum*. In the irregular development of the peripheral vesicular zone, however, this form shows a resemblance to *Caninia cylindrica*, mut. γ; hence the specific denomination.

Resemblances and differences.—*Campophyllum Murchisoni*, Edwards & Haime, as represented in 'Monogr. Brit. Foss. Corals' (Palæont. Soc.) pt. iii (1852) p. 184 & pl. xxxvi, fig. 3, differs considerably from our form, in the following characters:—much larger size, more numerous septa, the absence of a septal break,[1] and the

[1] These authors state that specimens of *Campophyllum Murchisoni* are in the Bristol Museum. Through the kindness of Mr. H. Bolton, F.R.S.E., the Curator of that Museum, I have had the opportunity of examining a specimen, which agrees almost exactly with pl. xxxvi, fig. 3, of their monograph, but possesses a septal break precisely similar to that shown by *Campophyllum caninoides*.

reticulate structure of the peripheral area, which is discontinuously radiated by the septa.

Campophyllum aff. *Murchisoni*, Edwards & Haime, Vaughan, Proc. Bristol Nat. Soc. n.s. vol. x (1903) p. 116 & pl. i, fig. 5, differs from our species only in the feebler definition of the septal break and the wide, uniformly-thick zone of vesicles. This form, however, was obtained[1] from the *Dibunophyllum*-Zone (Avon section).

A Campophyllid. (Pl. XXXI, fig. 3.)

Horizontal section.—Outer wall strong. The wide peripheral area, consisting of several rows of large, compressed vesicles, is not radiated by the septa, and shows no septal projections; it passes imperceptibly into the narrow, variable external area, which is radiated by the septa and crowded with interseptal vesicles. The inner boundary of the external area forms a somewhat feebly-defined inner wall.

The septa, 60 in number, are flexuous, thin, and all approximately equal in length: they stop short of the centre, leaving a central area which is occupied only by a few curved tabular intersections. The septa are festooned with tabular intersections in the medial area.

Intermediate septa practically absent; represented only by very few, minute projections from the inner wall.

A well-marked septal break, formed by the shortening of one or more septa, gives an appearance of bilateral symmetry to the section. A fossula is indicated at this point, by the inward shift of the tabular intersections, which form a series of arches.

Vertical section.—The tabulæ are broad plates, practically flat in the centre, and bending downward within the septal zone. A majority of them stretch completely across, but some are not so continuous, and form very broad, flattened vesicles.

The outermost zone consists of several vertical rows of ascending vesicles.

Remarks.—The affinities of this coral, which occurs in the Upper *Dibunophyllum*-Zone of the Mendip area, are somewhat obscure, though its nearest allies are, certainly, the *Campophylla*. The form is, I think, of sufficient importance to be described and figured; but the discussion of its affinities is best deferred, until the collection of more material has thrown further light on the subject.

Clisiophyllids.

Carcinophyllum.

Carcinophyllum mendipense, sp. nov. (Pl. XXXI, fig. 4.)

Form: conical.

Horizontal section.—Central area circular and strongly-bounded. Mesial plate, when present, short and thick. The structure of the central area is essentially radial, the number of the

[1] *Fide* the late W. W. Stoddart.

radial lamellæ being equal to, or greater than, that of the primary septa. The lamellæ are joined by a few concentric tabular intersections.

The primary septa, generally 30 to 32 in number, are stout and well-spaced; they do not extend to the outer wall.

The secondary septa are short and thick, with club-shaped outer ends; they project inwards from the thick inner wall. This inner wall, which constitutes a prominent feature, is formed partly by the thickening of both series of septa, and also, in a considerable degree, by the deposit of secondary matter.

A septal break, though not always distinguishable, is often marked by the stronger development of one of the secondary septa.

The peripheral area, which is rarely preserved, is narrow and variable, and is composed of large, compressed vesicles. It is not radiated by the septa.

The strong outer wall shows regular septal projections.

Discussion.—The genus *Carcinophyllum*, as defined by James Thomson, Proc. Phil. Soc. Glasgow, vol. xiv (1883) p. 455, possesses all the essential characters of the form under description, differing only in the more irregular structure of the central area. The character of the central area, however, varies so much in different sections of our species, that this point of difference is one of little importance.

Resemblances and differences.—*Carcinophyllum mendipense*, which characterizes the Lower *Seminula*-Zone in the Mendip area,[1] resembles *Carcinophyllum* θ,[2] which characterizes the Lower *Dibunophyllum*-Zone, in all essential structural characters, and the two forms are, undoubtedly, members of the same gens. The important points of difference are:—(1) The much greater development, in *Carcinophyllum* θ, of the peripheral vesicular zone. (2) The strong development, in *C. mendipense*, of the thick, ring-like inner wall. These differences of structure have an evolutionary significance; both the strong development of the vesicular zone, and the type of septation, seen in *Carcinophyllum* θ, indicate an approach to the structural form typified by *Lonsdalia*.

Cyathophylloid Clisiophyllids.

(Pl. XXXI, figs. 5 *a* & 5 *b*.)

Small, cylindrical or cylindro-conical corals, which exhibit a simple type of Clisiophylloid structure, in common with certain well-marked Cyathophylloid characters, occur commonly in the Lower *Seminula*-Zone of the Eastern Mendips.[3]

[1] And in the Weston-super-Mare district also. The figured specimen was obtained from this district.

[2] A. Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 285 & pl. xxiv, figs. 3–3 *b*.

[3] The earliest Clisiophyllids appear in the *Syringothyris*-Zone. Their characters are described by Dr. A. Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 286.

These Clisiophyllids show considerable variation. Pl. XXXI, fig. 5 *b*, illustrates a specimen in which the Cyathophylloid characters are strongly-marked, while fig. 5 *a* of the same plate illustrates a type with a more markedly Clisiophylloid structure.

Affinities.—The Clisiophylloid character is exhibited in:—

A simple Clisiophylloid structure in the central area. In a horizontal section, the central area is small and compressed; the mesial plate is well-developed, and the concentric tabular intersections are strong and closely packed, but the radial lamellæ are few and discontinuous. These characters indicate a central vaulting up of the tabulæ, into tall, laterally-compressed cones, which are feebly radiated by lamellæ, but conspicuously crested.

The Cyathophylloid character is shown by:—

The nature of the septa. The primary septa are numerous and flexuous; they run inward almost, if not quite, to the central area, and outward to the thin outer wall. The secondary septa are generally well-developed.

The crowded interseptal vesicles in the medial area, which is radiated by the primary septa only.

Clisiophyllum.

CLISIOPHYLLUM aff. CURKEENENSE, Vaughan.

A form, similar to that which is being described and figured [1] by Dr. A. Vaughan, occurs in the Lower *Dibunophyllum*-Zone of the Mendip area.

Cyclophyllum.

CYCLOPHYLLUM PACHYENDOTHECUM, Thoms., mut.

Compare James Thomson, Proc. Phil. Soc. Glasgow, vol. xiv (1883) p. 493 & pl. xiv, fig. 1.

It will be better to await more material, before attempting to describe the detailed characters of our form, which occurs commonly in the Upper *Dibunophyllum*-Zone of the Mendip area.

(ii) BRACHIOPODS.

Productus.

PRODUCTUS CONCINNO-MARTINI.

Compare Davidson, 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63) pl. xliii, fig. 10. (*Productus semireticulatus*, var. *concinnus*.)

In this form, which occurs commonly in the *Syringothyris*-Zone of the Mendip area, the convex valve forms a depressed vault over the flat portion of the concave valve. A section of the valve, taken through the hinge-line, is quadrate, not transverse.

As suggested [2] by Dr. A. Vaughan, this form may probably be traced back to *Productus* cf. *Martini*. Further material and much careful investigation will be necessary, however, before the true relationships of this and other allied forms [3] can be settled with definiteness.

[1] In the present number of the Quarterly Journal, p. 320 & pl. xxx, figs. 2 & 2 *a*.

[2] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 289.

[3] For example, the strongly-spinose mutation (*Productus* cf. *semireticulatus*, mut. S_1) which abounds in the Lower *Seminula*-Zone.

Productus concinnus (Sow.), mut. D_2. (Pl. XXXII, figs. 3 *a* & 3 *b*.)

Convex valve.—The rostral portion of the valve forms a more or less rectangular, flattened, transverse area. The medial area is flattened and broadly-sulcate.

The sides are steep, but not square-cut, the shell spreading out in a skirt-like extension. The ribs are fine on the rostral portion of the valve, becoming broader on the 'skirt.' Semireticulation is strongly marked on the wings, but somewhat indistinct over the medial area. Spines are few and scattered on the main part of the valve, but more numerous on the flanks.

Discussion.—In this form, the convex valve forms a strongly-arched vault over the flat portion of the concave valve; and a section of the convex valve, taken through the hinge-line, is transverse and more or less rectangular.

Our form, which characterizes the Upper *Dibunophyllum*-Zone of the Mendip area, agrees very closely with the type[1] of *Productus concinnus*, figured by Sowerby in 'Min. Conch.' vol. iv (1823) pl. cccxviii, fig. 1 (left-hand figure only).

Variation.—Variants, of the form here described and figured, towards *Productus costatus*, J. Sow., are very common. These are characterized by an irregular development of strong, broad ribs on the anterior part of the shell, and by the conspicuous development of rows of spines on the alate flanks.

Productus ϕ. (Pl. XXXII, fig. 2.)

General characters.—Hinge-line usually less than, never exceeding, the width of the shell. Shell transverse, large, often very large. Test moderately thick.

Convex valve.—The body of the valve is globose; longitudinal convexity greater than transverse convexity. The beak is broad, but narrows rapidly to its apex. The medial area slopes gradually and imperceptibly into the wings, which are cylindrically rolled but not produced. The wings are generally smooth, but occasionally show very faint concentric wrinkles, which never extend far onto the flanks. A row of short, curved spines projects from the hinge-line. The ribbing is close-set and regular, and the spacing of the ribs is maintained uniform by the intercalation of fairly regular series of intermediate ribs.

Resemblances and differences.—From its large size, broad beak, and cylindrically-rolled wings, *Productus* ϕ might often be recorded as *Pr. giganteus*. But *Pr. giganteus*, as represented in Davidson's 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63) pls. xxxvii–xxxviii, & pl. xxxix, figs. 1 & 4, differs from

[1] I am greatly indebted to Dr. A. Vaughan, who (having recently examined the type-specimen, preserved in the Natural History Museum) has placed the results of his investigation at my disposal.

Productus ϕ in the following characters:—(1) Broader beak; (2) produced wings; and (3) irregular and flexuous ribbing.

From *Pr. hemisphericus*, *Pr.* ϕ differs in its larger size, more transverse form, and in the feebler definition of the wings.

Evolution.—*Pr.* ϕ, which is highly characteristic of the Upper *Dibunophyllum*-Zone in the Mendip area, was most probably formed by direct evolution from *Pr. hemisphericus.*

Productus sp., convergent with *Pr. margaritaceus*, Phil. (Pl. XXXII, fig. 4.)

Convex valve.—Shell small, strongly convex, transverse. Beak small, pointed, and arched. Wings well-marked, but not sharply separated from the rest of the valve. Ribs well-spaced, broad and rounded; increasing almost entirely by the intercalation of fresh ribs, but also by very occasional forking; the fresh ribs rapidly attain the thickness of the earlier ones. Spines few and scattered on the main part of the valve, but numerous on the ears and hinge-line.

Discussion.—This well-marked form, which occurs in the Upper *Dibunophyllum*-Zone of the Mendip area, has a strong general resemblance to *Pr. margaritaceus*, Phil., as represented in Davidson's 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63) pl. xliv, figs. 5-6 *a*. The general form of the shell, the pointed, arched beak, and the disposition of the spines on the wings, are points of marked similarity. In the character of its ribbing, however, our form differs considerably from *Pr. margaritaceus*, which has flattened ribs, increasing mainly by forking.

Productus aff. elegans, M'Coy.

Specimens occurring in the *Dibunophyllum*-Zone of the Mendip area are practically identical with *Pr. elegans*, as described and figured by M'Coy, in 'Brit. Pal. Foss.' 1855, p. 460 & pl. iii h, fig. 4.

Chonetes.

Chonetes aff. comoides (J. Sow.).

Compare Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 295 & pl. xxvi, fig. 4.

The form abounding in the Lower *Dibunophyllum*-Zone of the Mendips is identical with that which characterizes the same horizon in the Bristol area.

The form which occurs abundantly at the top of S_1 and the base of S_2 in the Mendip area is practically identical with the D_1 form in external characters; but the shell is thinner, and the muscular impressions much shallower, in the *Seminula*-Zone form.

The specimens of *Chonetes* aff. *comoides* which occur commonly

in the Upper *Dibunophyllum*-Zone of the Mendips possess well-developed area and tubuli, and exhibit the characteristic pitting of the under-layer of the test. In their strongly-convex form and very thick shell, however, they differ from the D_1 specimens and resemble *Daviesiella* (*Productus*) *llangollensis* (Dav.) 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63) pl. xlv, figs. 1–6 & pl. lv, fig. 9.

Athyris.

Athyris (Actinoconchus) cf. lamellosa (L'Éveillé). (Pl. XXXII, figs. 1 *a* & 1 *b*.)

The Mendip specimens, which are all obtained from the Upper *Cleistopora*-Zone, occur crushed in shale, so that their original form is somewhat obscured. The mesial fold is slight, and starts at some distance from the beak, while the mesial sinus is only suggested on the anterior portion of the pedicle-valve.

The concentric shell-expansions are excellently preserved in the majority of specimens. They consist, in adult specimens, of about 16 strong, smooth lamellæ which, when broken off at the base, leave strong concentric ridges on the shell; between these main expansions, and especially well developed on the marginal portion of the valves, are numerous similar but finer expansions, which, when broken off, are represented by very fine concentric ridges.

The figure in Davidson's 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63) which most closely represents our form is pl. li, fig. 14; but the specimen there depicted is less transverse than our form, and further shows a marginal sinus in the brachial valve, which none of our specimens possess.

Athyris cf. glabristria (Phil.).

= *Cliothyris glabristria* & mut., Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 297, 298.

Further collecting and much detailed work will be necessary before the numerous mutational forms included in this comprehensive gens can be described with profit. For the present, the several mutational forms are merely recorded in the faunal lists as *Athyris* cf. *glabristria*, mut. Z_1, mut. Z_2, &c.

In all our forms, the concentric shell-expansions consist of a narrow, basal plate, which passes into a fringe. The width and thickness of the basal plate vary considerably in different specimens.

Athyris cf. expansa (Phil.), Davidson.

Compare Davidson, 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63) p. 82 & pl. xvi, figs. 14, 16, 17, pl. xvii, figs. 3, 3 *a*.

Our specimens show considerable variation in form. The commonest form in the Mendip area is most closely represented by

pl. xvii, figs. 3 & 3 *a*, of Davidson's monograph, but some specimens approach pl. xvi, fig. 17 in transversity.

I am unable to distinguish the specimens occurring in the *Dibunophyllum*-Zone from those in the *Syringothyris*- and *Seminula*-Zones, and I am ignorant of the nature of the shell expansions, which are not preserved in any of my specimens. The fine concentric ornamentation of the shell, however, renders it very unlikely that the expansions were strong lamellæ.

Athyris cf. planosulcata (Phil.), Davidson.

The common form in the Lower *Seminula*-Zone of the Mendip area is closely represented, in general shape, by pl. xvi, figs. 4–4 *b* of Davidson's 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63). But, although I have no direct evidence as to the nature of the shell-expansions in our form, the fine concentric ornamentation of the valves renders it almost certain that these expansions were not strongly lamellar, as they are in the typical form of *Athyris* (*Actinoconchus*) *planosulcata*.

Reticularia.

Reticularia cf. reticulata, M'Coy.

=*Reticularia* aff. *lineata*, Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 299.

Compare M'Coy, 'Syn. Carb. Limest. Foss. Ireland' 1844, p. 143 & pl. xix, fig. 15, and Davidson, 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63) pl. xiii, figs. 13 & 13 *a*. (*Spirifera lineata*, var. *reticulata*.)

The Mendip form closely resembles M'Coy's type-figure, though an average specimen from the Mendips is larger than the type. The strong dental plates, combined with the well-developed area and the reticulate structure of the test, characterize our form as a typical *Reticularia*.

This form undergoes little mutational change throughout its long range in the Mendip sequence; but it is important, as being an essentially-Clevedonian fossil.

Spirifer.

Spirifer cf. bisulcatus, J. Sow.

Specimens occurring commonly in the *Syringothyris*-Zone, and more rarely in the Lower *Seminula*-Zone, of the Mendip area show a general resemblance to the type of *Spirifer bisulcatus*, as figured in Davidson's 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii. (1858–63) pl. vi, figs. 6–9; poorness of material prohibits a detailed description of our form.

The few specimens that I have obtained from the Upper

Dibunophyllum-Zone are somewhat fragmentary, but they appear to be closely similar to the lower form.

SPIRIFER cf. FURCATUS, M'Coy.

The Mendip form, which occurs very abundantly at the base of the *Seminula*-Zone at Cheddar, agrees very closely with M'Coy's description and figure, in 'Syn. Carb. Limest. Foss. Ireland' 1844, p. 131, and pl. xxii, fig. 12. It is very abundant at the same horizon in the Weston-super-Mare district.

Spiriferina.

SPIRIFERINA cf. OCTOPLICATA (Sow.).

= *Spiriferina octoplicata*, Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 300 & pl. xxvi, fig. 6.

Syringothyris.

SYRINGOTHYRIS aff. CUSPIDATA (Mart.).

S. aff. CUSPIDATA, mut. K.

= *S.* aff. *cuspidata*, Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) p. 301.

S. aff. CUSPIDATA, mut. C.

= *S. cuspidata*, Vaughan, *ibid.*

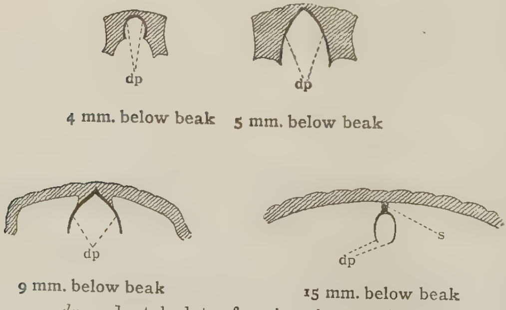
Camarophoria.

CAMAROPHORIA ISORHYNCHA (M'Coy). (Pl. XXXII, figs. 5 *a*–5 *c*.)

M'Coy, 'Syn. Carb. Limest. Foss. Ireland' 1844, p. 154 & pl. xviii, fig. 8 (*Atrypa isorhyncha*), & 'Brit. Pal. Foss.' 1855, p. 444; Davidson, 'Monogr. Brit. Foss. Brachiop.' (Palæont. Soc.) vol. ii (1858–63) p. 117 & pl. xxv, figs. 1–2 *b*.

Fig. 2.—*Pedicle-valve* of Camarophoria isorhyncha.

(*Horizontal sections, natural size, showing the internal characters.*)



dp = dental plates forming the spondylium.
s = mesial septum.

This species is highly characteristic of the base of the *Seminula*-Zone in some localities, namely, Cheddar in the Mendip area, and the Weston-super-Mare district. Our specimens closely resemble the figured type in general form, dimensions, and all essential characters, but differ in the possession of a much more prominent mesial fold; the fold invariably consists of four ridges, and the sinus always contains three ridges.

Internal characters.—Pedicle-valve (text-fig. 2, p. 376): Dental plates large, converging and forming a spondylium, which extends throughout half the length of the valve. The crest of the spondylium is fused with the bottom of the valve throughout the greater part of its length; but anteriorly it is united to the valve by a low, strong mesial septum, which does not extend far beyond the anterior end of the spondylium.

Brachial valve: Mesial septum and cardinal process well-developed.

EXPLANATION OF PLATES XXXI-XXXV.

Plate XXXI.

[All the figured specimens are preserved in the Author's collection.]

Fig. 1. A Caninoid *Cyathophyllum* (p. 367). Horizontal section; ×1·17.
Syringothyris-Zone; Vallis-Vale section, near Frome (Somerset).

Figs. 2 *a* & 2 *b*. *Campophyllum caninoides*, sp. nov. (p. 368).
Fig. 2 *a*. Horizontal section; natural size.
Upper *Syringothyris*-Zone, Leigh-upon-Mendip (Somerset).
Fig. 2 *b*. Horizontal section; ×1·16.
Upper *Syringothyris*-Zone; Stoke Lane (Somerset).

Fig. 3. A Campophyllid (p. 369). Horizontal section; ×1·18.
D_2 subzone; Emborough (Somerset).

Fig. 4. *Carcinophyllum mendipense*, sp. nov. (p. 369). Horizontal section; ×1·22.
Base of *Seminula*-Zone; Milton-Road Quarries, Weston-super-Mare (Somerset).

Figs. 5 *a* & 5 *b*. Cyathophylloid Clisiophyllids (p. 370).
Fig. 5 *a*. Horizontal section; ×1·2.
S_1 subzone; Vallis-Vale section, near Frome (Somerset).
Fig. 5 *b*. Horizontal section; ×1·5.
S_1 subzone; Holwell (Somerset).

Plate XXXII.

[All the figured specimens, with one exception, are preserved in the Author's collection.]

Figs. 1 *a* & 1 *b*. *Athyris (Actinoconchus)* cf. *lamellosa* (L'Eveillé) (p. 374).
K_2 subzone; Maesbury railway-section (Somerset).
Fig. 1 *a*. Pedicle-valve; ×1·08.
Fig. 1 *b*. Another specimen. Brachial valve; natural size.

Fig. 2. *Productus* ϕ (p. 372). Convex valve; natural size.
D_2 subzone; Emborough (Somerset).

Figs. 3 *a* & 3 *b*. *Productus concinnus* (Sow), mut. D_2 (p. 372). Convex valve; natural size.
D_2 subzone; Emborough (Somerset).

Fig. 4. *Productus* sp., convergent with *Pr. margaritaceus*, Phil. (p. 373). Convex valve; natural size.
D_2 subzone; Ebbor Valley, near Wells (Somerset).

Figs. 5 *a*–5 *c*. *Camarophoria isorhyncha* (M'Coy) (p. 376). Base of *Seminula*-Zone; Cheddar-Gorge section (Somerset).
Fig. 5 *a*. Brachial valve; natural size.
Figs. 5 *b* & 5 *c*. Another specimen (A. Vaughan Coll.).
5 *b*. Side view of both valves; natural size.
5 *c*. Pedicle-valve; natural size.

PLATE XXXIII.

Sketch-map, showing the outcrop of the Carboniferous Limestone (Avonian) in the Mendip area, on the scale of 4 miles to the inch.

PLATE XXXIV.

Range-diagram of corals in the Carboniferous Limestone (Avonian) of the Mendip area.

PLATE XXXV.

Range-diagram of brachiopods in the Carboniferous Limestone (Avonian) of the Mendip area.

DISCUSSION.

The PRESIDENT said that he had already expressed his interest in the application of Dr. Vaughan's work to other districts, and he congratulated the Author on the clearness with which he had presented his results to the Fellows.

Mr. W. A. E. USSHER complimented the Author on the working-out of the tectonic features of the Mendips, a point which was not contemplated in the resurvey of the area by himself and Mr. H. B. Woodward about 34 years ago. In view of the abnormal occurrence of Coal-Measures under the Carboniferous Limestone at Vobster, he desired to ask the Author as to the exact position of the borehole in the Ebbor Valley, in which Coal-Measures were said to have been struck.

Mr. H. B. WOODWARD wished that the Author had marked on the map the boundaries of the zonal divisions. With regard to the Ebbor district, he was quite prepared to accept the Author's reading of the structure, which differed from that to which he had been led in 1871; and he thanked the Author for dealing generously with the work of those who had preceded him.

Mr. E. E. L. DIXON congratulated the Author on the valuable results obtained by his determination in the Mendips of the zones instituted by Dr. Vaughan. In view of their proved general application in Western England, Wales, and Ireland, these zones might be considered as having passed beyond the probationary stage, and future advances would trend in the direction of determining by their means the physical conditions at various periods of Carboniferous time, and in unravelling the evolutionary connexion between successive faunas, as it was on this connexion that the value of the zoning method depended.

The district described was of especial interest to the speaker, as the change in the character of the *Syringothyris*-Zone, which was noted in passing northwards from it to Bristol, could be paralleled in Southern Pembrokeshire, where fossiliferous limestones in the lower part of the zone gave place northwards to a band of dolomites on the same horizon. Another point of interest was the absence of any sign, below the base of the Avonian, of the approach to the

marine conditions which existed during the deposition of the Devonian rocks of Devon.

In conclusion, the speaker enquired as to which of the volcanic horizons proved at Weston-super-Mare corresponded to the igneous rock at Uphill.

The Rev. H. H. Winwood said that he hoped that the zonal wave would continue to roll on, and that the admirable work done by Dr. Vaughan, and his able pupil the Author, amid the Carboniferous rocks of the West would be taken up by geologists in the North. He asked the Author whether there was any evidence of faulting in the limestone-rocks of the Ebbor Gorge besides the fact, as stated, of the break in the usual zonal succession. The absence or extreme paucity of the '*Modiola*'-phase in the Mendips was an argument for the use of the more general term *Cleistopora*. He noted some new terms again introduced—'Clevedonian,' 'Kidwellian,' and 'Avonian'—somewhat puzzling to older geologists. Would the two former stand the test of criticism? The last-mentioned designation, 'Avonian,' as representing the typical Western section, might perhaps be useful.

Mr. C. B. Wedd stated that, in Eastern Derbyshire, the coral- and brachiopod-faunas of the upper part of the Carboniferous Limestone agreed closely with the *Dibunophyllum*-Zone of Dr. Vaughan's classification. A better acquaintance with the latter and with the fauna of Eastern Derbyshire showed that this agreement was closer than he had supposed, and that all the Upper Limestone, at least down to the second bed of toadstone, could be assigned with confidence to the Upper *Dibunophyllum*-Zone (D_2). This included nearly the whole of the limestone exposed in the neighbourhood of Wirksworth, Cromford, Bonsall, Matlock, and Derby, and all the strata seen in the inliers of Crick and Ashover.

Sir Archibald Geikie expressed the pleasure which geologists in this country could not but feel that the reproach was now being removed that they had left the great Carboniferous Limestone of the British Islands without any attempt to subdivide it into palæontological zones. He hoped that, in introducing new stratigraphical terms, regard would be had to the detailed work of the Continental geologists, particularly those of Belgium, in the Carboniferous Limestone.

The Author thanked the Fellows for their kind reception of his paper. In answer to Mr. Dixon, he stated that the igneous rock at Uphill was associated with Upper *Zaphrentis*-Beds, and therefore occurred at the lower of the two volcanic horizons. Replying to the Rev. H. H. Winwood, he explained that, although the exposures north-east of the Ebbor Valley did not furnish any direct proof of the existence of a fault between the Upper *Dibunophyllum*-Beds and the Lower *Seminula*-Beds, such evidence as there was undoubtedly favoured that view. The terms Clevedonian and Kidwellian had been suggested by Dr. Vaughan for the lower and upper stages, respectively, of the Avonian, because it was not

possible to correlate accurately these two stages, as defined in the South-West of England and South Wales, with the Tournaisian and Viséan stages of the Belgian geologists. The *Syringothyris*-Zone formed the uppermost part of the Clevedonian in Dr. Vaughan's scheme, but the equivalent part of the Belgian sequence was included in the Viséan by the Belgian geologists. In answer to Sir Archibald Geikie, the Author stated that the work of the Belgian geologists had received full attention in Dr. A. Vaughan's paper [1] on the Bristol area: a correlation of the Bristol sequence with the Belgian sequence was contained in that paper.

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 255–57.

FIG. 1.

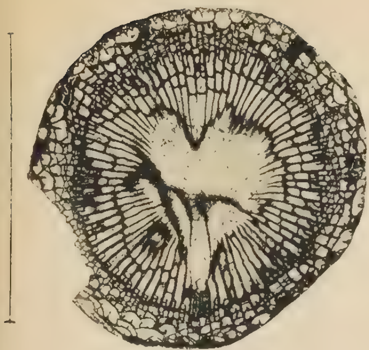


FIG. 2A.

FIG. 3.

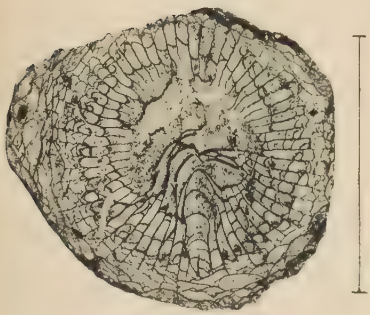


FIG. 2B.

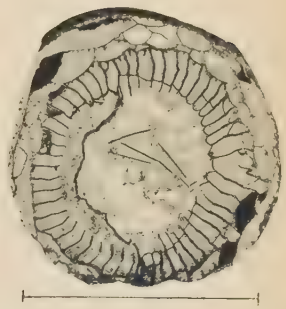


FIG. 4.

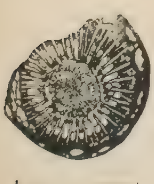


FIG. 5A

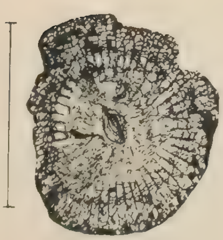


FIG. 5B.

AVONIAN CORALS FROM THE MENDIP AREA.

J. W. Tutcher, Photo. *Bemrose. Collo.*

FIG. 1A.

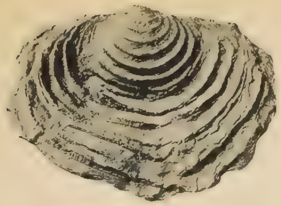


FIG. 1B.

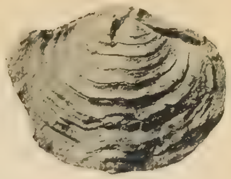


FIG. 2.

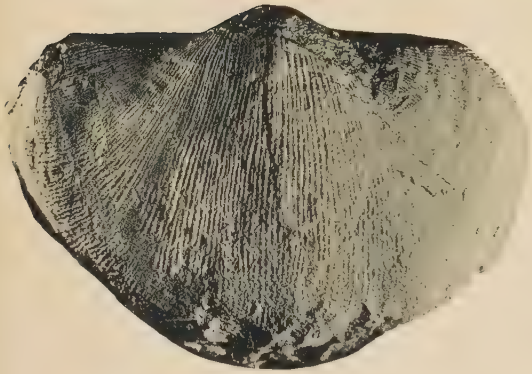


FIG. 3A.

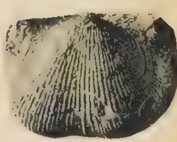


FIG. 4.

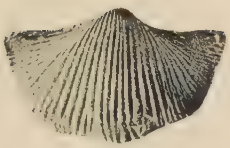


FIG. 3B.

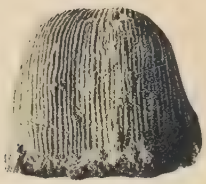


FIG. 5A.

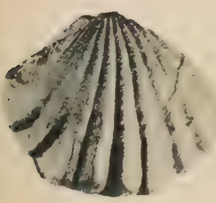


FIG. 5B.

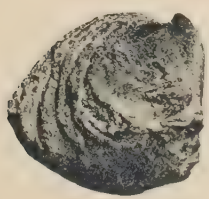
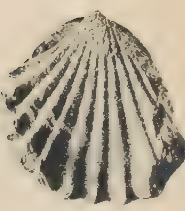
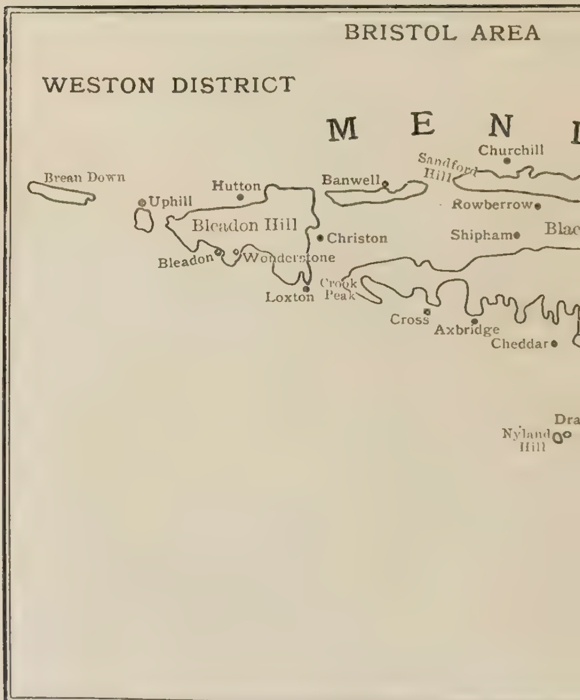


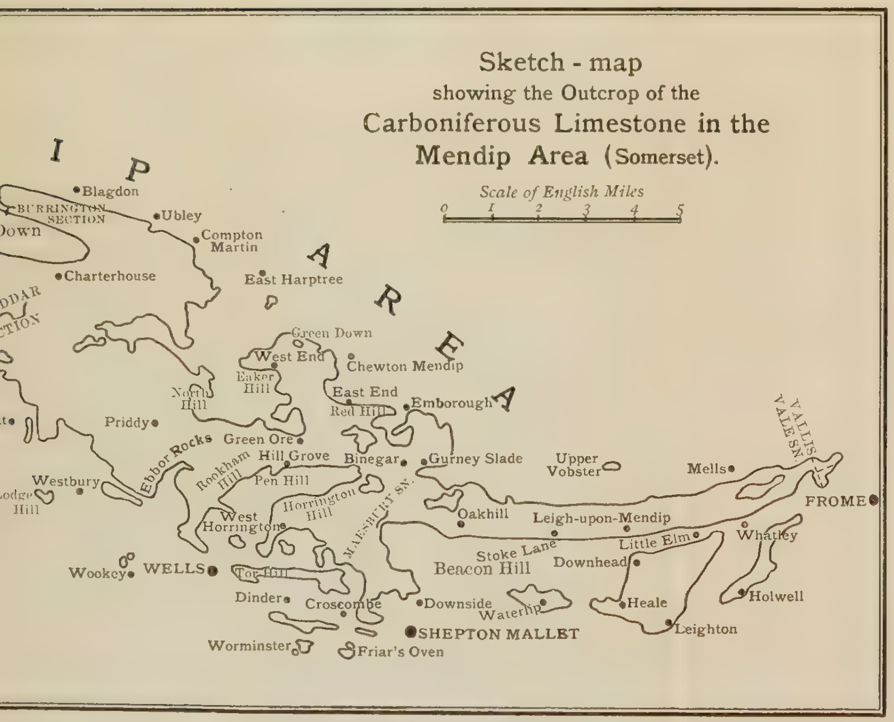
FIG. 5C.



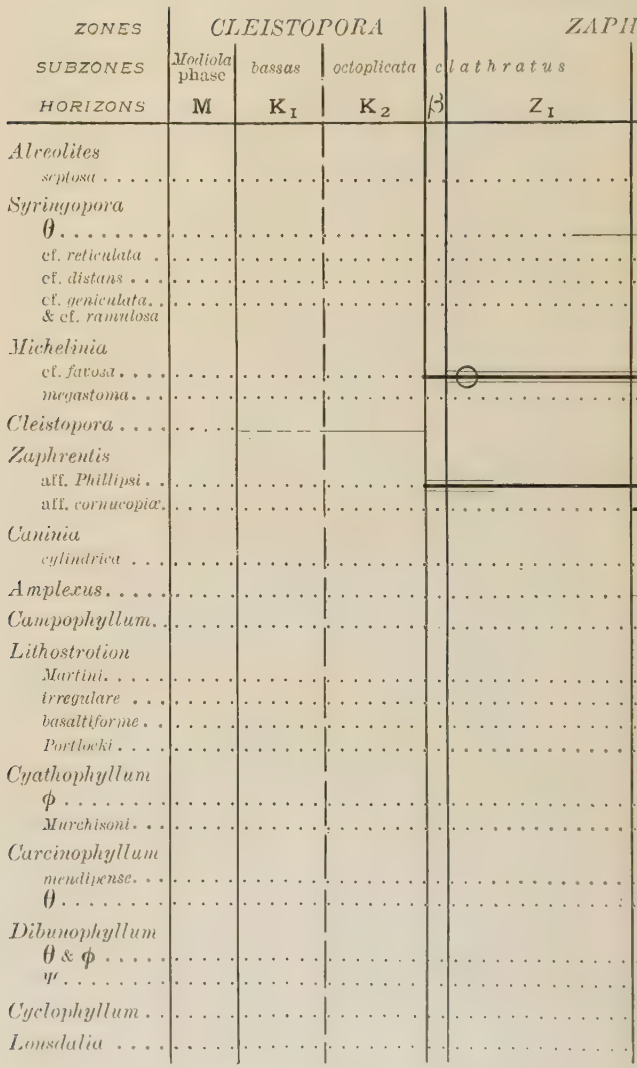
AVONIAN BRACHIOPODS FROM THE MENDIP AREA.

J. W. Tutcher, Photo. *Bemrose Collo.*


BRISTOL AREA
WESTON DISTRICT
M E N
Brean Down
Uphill
Hutton
Bleadon Hill
Bleadon
Wonderstone
Loxton
Banwell
Sandford Hill
Churchill
Rowberrow
Christon
Shipham
Crook Peak
Cross
Axbridge
Cheddar
Nyland Hill

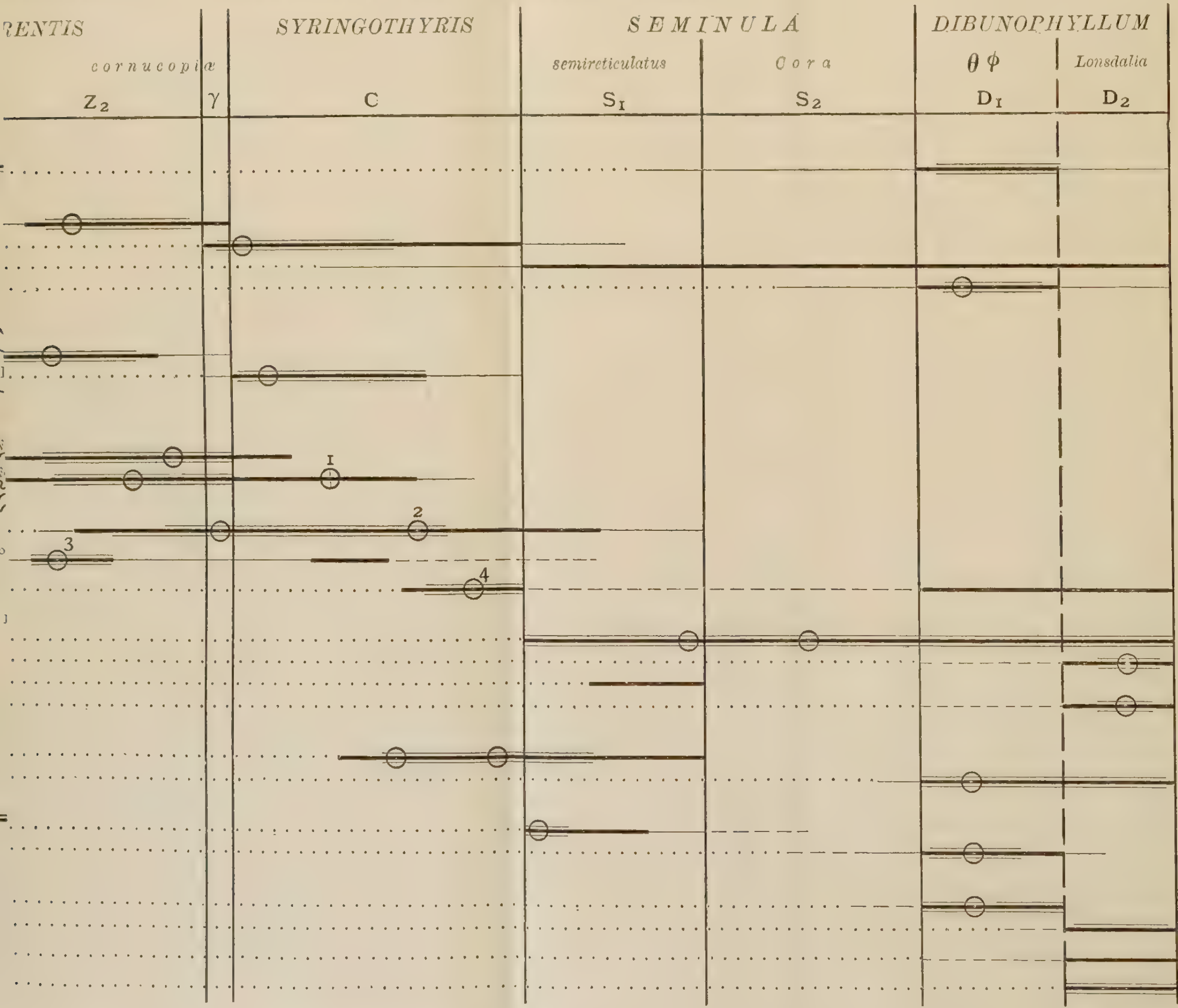

Sketch - map
showing the Outcrop of the
Carboniferous Limestone in the
Mendip Area (Somerset).
Scale of English Miles
0 1 2 3 4 5
I P
A R E A
Blagdon
BURRINGTON SECTION
Ubley
Compton Martin
Charterhouse
East Harptree
Green Down
West End
Chewton Mendip
Eaker Hill
North Hill
East End
Red Hill
Emborough
Priddy
Ebbor Rocks
Green Ore
Rookham Hill
Hill Grove
Binegar
Gurney Slade
Upper Vobster
Mells
VALLIS VALE SN.
FROME
Westbury
Lodge Hill
Pen Hill
Horrington Hill
MAESBURY SN.
Oakhill
Leigh-upon-Mendip
West Horrington
Whatley
Little Elm
Stoke Lane
Beacon Hill
Downhead
Wookey
WELLS
Tor Hill
Dinder
Croscombe
Downside
Waterlip
Heale
Holwell
Leighton
SHEPTON MALLET
Worminster
Friar's Oven

RANGE-D



Notes:- 1. *Zaphrentis* aff. *cornucopiæ*, mut. C. 2. *Caninia*
3. *Amplexus* cf. *coralloides*. 4. *Campophyllum ca*

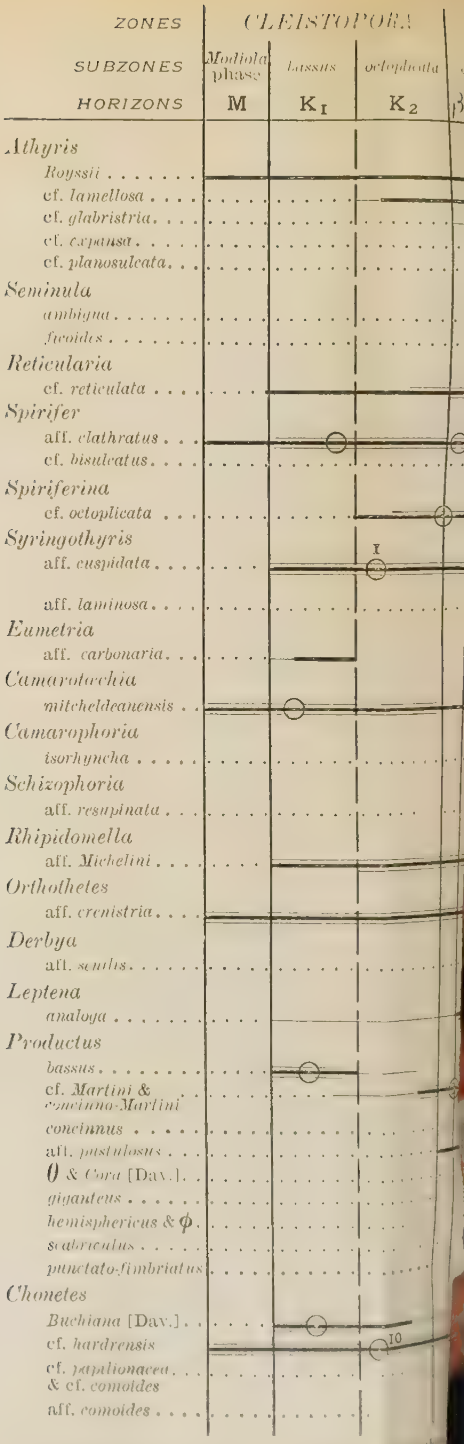
IAGRAM OF CORALS IN THE MENDIP AREA.



cylindrica. mut. S_1.
moides.

The circles indicate approximate positions of maxima. Thin continuous lines indicate rarity.
Thick continuous lines indicate common occurrence. Two or three parallel lines indicate abundance.

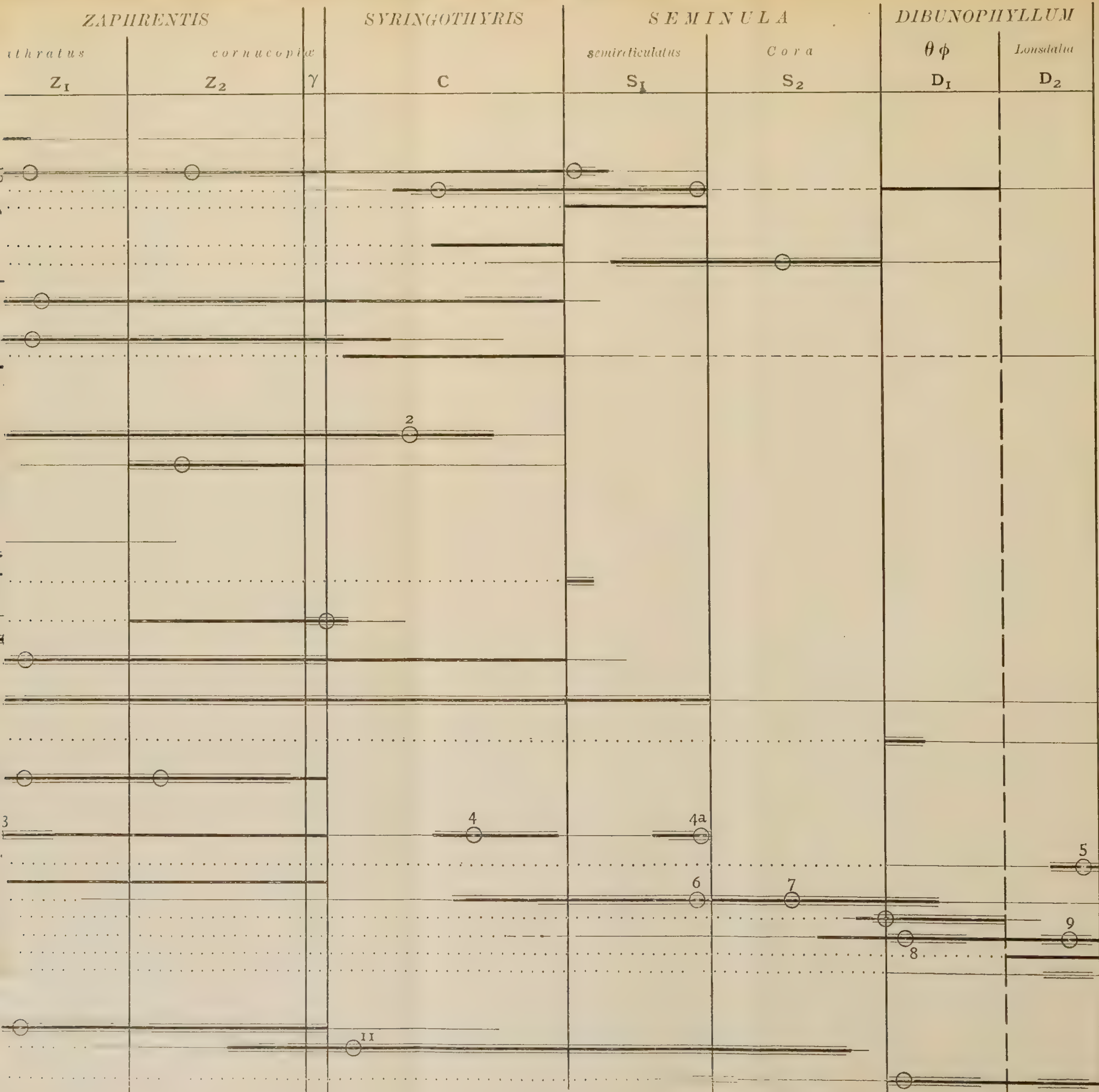
RA



For explanation of the conventional signs see the diagram of Corals.

Notes:- 1. Syringoth...
2. Syringoth...
3. Productus...

[R]GE-DIAGRAM OF BRACHIOPODS IN THE MENDIP AREA.



aff. *cuspidata*. mut. K.
aff. *cuspidata*. mut. C.
Martini.

4. *Productus concinno-Martini*.
4a. *Productus* cf. *semireticulatus* mut. S_1 (spinous form)
5. *Productus concinnus*. mut. D_2

6. *Productus* θ
7. *Productus Cora*. [Dav.] mut. S_2
8. *Productus hemisphericus*.

9. *Productus* φ
10. *Chonetes* cf. *crassistria*.
11. *Chonetes* cf. *comoides*.

15. *The* GEOLOGY *of* DUNEDIN (NEW ZEALAND).

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[PLATES XXXVI–XXXIX.]

CONTENTS.

I. INTRODUCTION, AND DESCRIPTION OF THE TOPOGRAPHY OF THE AREA.

THE eastern coast of the South Island of New Zealand has two projecting points consisting of volcanic rocks of Kainozoic age. These igneous masses constitute Banks Peninsula and the Otago Peninsula. Except in regard to their physiographical nature, neither of these areas has been submitted to accurate geological examination, although enough work has been done to show that both of them offer a most interesting field for petrographical study.

The general structure of Banks Peninsula was studied by Sir Julius von Haast,[1] who traced and described various crater-walls which were the boundaries of the foci of most intense volcanic activity. The structure of one of these—Lyttelton Harbour—was displayed with great clearness in the walls of the railway-tunnel that pierced it, and Sir Julius has given an accurate description of this.

Many of the rock-specimens collected during the tunnel-driving were described and figured by the officers of the French Campbell-Island Expedition. Other rock-specimens from the district have been described by Marshall,[2] Speight,[3] and Ulrich.[4]

So far as its general structure is concerned, Otago Peninsula has received less notice, though brief descriptions have been given by Hutton,[5] Hector, and Ulrich.[6] More detailed work has been devoted to the Otago-Peninsula rocks, and some types were described by Hutton, and later, in a far more elaborate manner, by Ulrich, who was the first to recognize the specially-interesting series of alkaline rocks that occurs here.

[1] 'Geology of Canterbury & Westland' 1875.

[2] 'Tridymite-trachyte of Lyttelton' Trans. N. Z. Inst. vol. xxvi (1893) p. 368.

[3] 'On a Doleritic Dyke at Dyers Pass' *Ibid.* p. 408.

[4] 'On the Occurrence of Nepheline-bearing Rocks in New Zealand' Rep. Austral. Assoc. Adv. Sci. vol. iii (1891) p. 127.

[5] 'Geology of Otago' 8vo. Dunedin, 1875.

[6] Rep. Austral. Assoc. Adv. Sci. vol. iii (1891).

In the present paper an attempt will be made to deal more fully with this Otago district, although it must at once be stated that the result should be regarded only as a breaking of the ground of an area that will afford abundance of inspiring work for several generations of geologists, who will here find material in plenty and in astonishing variety for testing theories in regard to magmatic differentiation or other agencies controlling the nature of volcanic emissions.

Position and Surface-Features.

The Otago Peninsula forms a prominent projection from the southern portion of the eastern coast of the South Island of New Zealand, in latitude 45° 52′ S. and longitude 170° 31′ 30″ E. It extends for 14 miles from north-east to south-west, but is nowhere more than 6 miles wide. It is united to the mainland at its south-western extremity by a narrow strip of sand, about a mile long and a mile wide, of recent accumulation. Its coast-line is irregular, and where fronting the Pacific Ocean the land rises at most of the headlands abruptly, often vertically, to a height of 300 or 400 feet. The greatest height of cliff is found at Highcliff, the top of which is 800 feet above sea-level. The indentations in this coast-line are fringed by a beach of white quartz-sand, which is constantly travelling northward under the influence of the heavy northward-setting seas and current. Two inlets are of especial size—Hooper's Inlet and Papanui Inlet, each 2 miles long by 1 wide. They are extremely shallow over nearly all of their extent, and flat muddy bottoms are exposed at low tide. The entrances are almost closed by large flat expanses of sand, rising here and there into dunes. The sand-flat is in each case on the north side of the inlet, and a narrow channel extends between it and the rocky cliffs that form the south side of the entrance.

Similar sand-flats, with their surface ranging to 20 feet above high-water level, are found in all the sheltered bays. In most cases, they completely fill the bay right up to its rock-walls, but occasionally, as at Tomahawk, a lagoon is formed whence the rainfall escapes over a depression in the sand-barrier; and through this the sea-waves may wash into the lagoon during periods of high tides or heavy weather.

The coast-line of the peninsula that forms the south-eastern border of Otago Harbour has sloping sides ending in short cliffs. Four miles from the north-eastern point—Taiaroa Head—a sandy beach extends north-eastward for 3 miles; and the sand from a portion of this—the Rauone beach—has been blown by the south-westerly winds right over the peninsula, here half-a-mile wide and 400 feet high, into a bay on the opposite sea-coast. The whole of this inner coast-line has numerous small bays and headlands; all of the bays are shallow, and much mud-flat is exposed at low tide. One peninsula—at Portobello—projects outward for a full mile at right angles to the coast.

The surface of the Peninsula is hilly, in places almost mountainous. The highest elevations are: Mount Charles (Moehau) 1340 feet, Sandy Mount 1068 feet, and Harbour Cone 1044 feet; but several other elevations rise above 1000 feet. These elevations are separated by deep V-shaped valleys, with steep thalwegs that terminate in sandy flats on the ocean-coast, or at the apices of the mud-flats running into the harbour-bays.

With the exception of one or two small outcrops, the Peninsula is built up exclusively of volcanic rocks.

The Otago Peninsula is not different in structure from that part of the mainland which is adjacent to it, nor from the coast-line extending 4 miles to the south and 10 miles to the north. Varieties of volcanic rock similar to those that form the Peninsula are found over all this extent, and they reach 8 miles inland. The whole of this district is a geological unit, the nature and structure of which are described in the following pages.

The description of the physiographical features of the Peninsula just given applies almost exactly to the rest of this district, although in both its northern and southern portions the various natural sections displayed in sea-cliffs and stream-valleys reveal a Kainozoic sandstone lying somewhat unconformably beneath the volcanic rocks. At the extreme limits of the district, the sandstone is seen to repose with a highly-unconformable junction upon the metamorphic rocks.

The coast-line immediately to the south of the Peninsula and to the north of Waitati, exhibits features rather different from those shown elsewhere in the district, for the Kainozoic calcareous sandstones are intersected by vertical joints; consequently, perpendicular cliffs without fringing beaches, but with outlying stacks, are frequent. North of the Peninsula, the sandy flats filling the smaller inlets are as characteristic as on the Peninsula itself. Murdering Beach, Kaikai's Beach, and Long Beach have an appearance closely similar to Sandfly Bay and Te Onepoto on the Peninsula. The larger inlets, again, have been converted into extensive tidal flats, with a sand-flat nearly closing the entrance. This is typically shown in Blueskin and Purakanui Bays.

The north-western shore of Otago Harbour has the same general characters as those mentioned in the description of the south-eastern side. The Port-Chalmers peninsula projects in a southerly direction, almost opposite the Portobello peninsula, which has a north-westerly trend. The width of the harbour is here still further contracted by the presence of two small islands (Quarantine Islands) between the two peninsulas. This chain of peninsulas and islands divides the upper from the lower harbour. The north-eastern entrance of the harbour is, as in the case of the other large inlets, partly closed by a sand-flat; but the tidal flow of water, assisted by the discharge of the numerous streams that flow into the harbour, is sufficient to keep a moderately-deep channel clear, so that vessels of large tonnage can enter and leave at suitable states of the tide.

The surface of this district is even more rugged than that of the

adjoining Peninsula, for the heights are greater and the valleys more profound. Mount Cargill (2232 feet), Flagstaff (2204), Signal Hill (1289), Swampy Hill (2195), Mihiwaka (1847), and Mopanui, are the more prominent elevations.

The more important streams are: the Kaikorai, flowing out to the south of the district; the Leith and North-East Valley streams, flowing into the head of Otago Harbour; the Waitati, flowing into Blueskin Bay; and the Waikouaiti, in the extreme northern portion of this district.

Origin of the Land-Forms.

The development of the physiographical features of the district requires only a brief explanation. In recent volcanic areas, the nature of the surface-features necessarily depends upon the varying intensity of volcanic action throughout the district. In all ordinary cases, the higher and more prominent elevations are the foci of eruption. As time goes on, and some of these elevations are removed by the ordinary processes of denudation, deep valleys may be eroded and the whole topography of the district changed, until it has the usual features found in all denuded land-areas. That this has occurred in the Dunedin area is evident at the first glance, for almost everywhere are missed the conical hills and craters that always distinguish the undestroyed volcanic districts.

In nearly every instance the upper portions of the valleys are steep and rocky, and the streams in them are small torrents. The lower portions are open and flat, with bottoms formed of gravels through which the streams meander.

The streams enter the sea at the heads of far-reaching bays, or in their lower course run over widespreading sand-flats. These bays and depressions, now filled with sand, are evidently in their origin valleys formed by the streams that now enter them, and, like the lower portions of the present valleys, must have been excavated when the land stood at a higher level relatively to the ocean than it does now.

This is most clearly seen in the case of Otago Harbour. It is at once clear that this is no hollow formed by explosion, as in Lyttelton Harbour and Akaroa Harbour in Banks Peninsula, but a depression that has been eroded by running water. The opposing peninsulas at Port Chalmers and Portobello, with the Quarantine Islands between them, mark the old watershed, whence one stream flowed north-eastward to Otago Heads, and the other south-westward to St. Clair. Depression converted these stream-valleys into sea-inlets, and its amount was sufficient to submerge the watershed separating their head-waters. The continual northward-setting drift and some movement of elevation finally blocked up the south-western entrance to the inlet with sand, and since then the outlet has remained constant at Otago Heads.

Additional evidence in favour of this view is afforded by the direction in which the bays opening into the harbour are directed.

In the Lower Harbour, or north-eastern part of the harbour, nearly all the bays point northward or eastward: as, for instance, Portobello Bay and Deborah Bay; though a few, such as Hamilton Bay, offer rather distinct exceptions. These northern and eastern directions are the natural directions that would result if the bays were the valleys of small tributary streams feeding the larger one that occupied the present depression of the lower harbour.

Similarly, the bays in the inner or Upper Harbour, such as Sauers Bay and Broad Bay, are directed nearly due south or west, and may easily represent the submerged valleys of streams tributary to the main river that flowed from Port Chalmers to St. Clair.

To the general rule in this district (that the upper portion of the stream-valleys are steep and rocky, and the lower portions open gravel-flats) there is one remarkable exception. This is found in the valley of the Leith Water. For the upper 2 miles of its course, this stream runs in the typical V-shaped steep rocky valley. For the next 4 miles the stream flows quietly over a gently-sloping valley with slowly-rising sides. Thence almost to its mouth, a distance of 5 miles, it flows with numerous cascades in a deep gorge, but for the last mile the bottom of this gorge is filled with recent gravels. In other words, the upper portion of this valley is still developing in the same way as all the other valleys of the district. Then there is a portion the development of which is mature, but the lower part is a gorge still in the very earliest stage of development. It is apparent that the course of this stream has been interrupted by some cause the effect of which has not yet spread back to that part of its valley which still shows the mature development.

The topography of the district at once gives a clue to the nature of this disturbing influence. The accompanying map (Pl. XXXVI) shows that the upper part of the Leith Valley is a direct continuation of the Kaikorai Valley. There is a well-defined mature valley behind Maori Hill; and a continuation of this can be traced over the reservoir-site to the Leith Valley, where indistinct terraces carry it forward to the Upper Leith, in which region the valley-form is mature. Throughout this distance, river-gravels are to be found in many places. This was apparently the bed of a stream that rose where the Leith now rises, the course of which coincided with that of the Leith as far as the reservoir, whence it flowed behind Maori Hill, and along the present Kaikorai Valley (which is now almost a dry valley) to the sea.

This stream appears to have been beheaded by a tributary of the North-East Valley-stream, which, rising at a source of the same altitude as that of the Leith, had a much shorter and therefore steeper course, and consequently eroded its valley more rapidly. The present gorge of the lower portion of the Leith is the valley of the intersecting tributary deepened and enlarged by the Leith waters. The beheading has occurred so recently, that the deepening of the valley resulting from its sudden shortening has not yet affected the upper portions of the old, more mature valley.

In the terminology proposed by Prof. W. M. Davis, these facts may be thus expressed. The North-East Valley and the Leith-Kaikorai valleys are those of consequent streams, resulting from the high elevation of the volcanic district. The lower part of the Leith gorge is a subsequent. The valley behind Maori Hill is an air-gap, and down this a more subsequent or obsequent stream flows into the Leith.

The submerged stream-valleys that now constitute the Upper and Lower Harbours, Hooper's and Papanui Inlets, are sufficient proofs of the fact that the district has been, within geologically-recent times, at a much higher level relatively to the sea. A minimum estimate of this previous elevation can be obtained by producing the actual slope of the sides of Otago Harbour at its narrowest point until the slopes meet at the bottom of a V-shaped valley. This would take place at a vertical depth of 900 feet below the present sea-level. The inlets are all of considerable breadth near their entrances, and may possibly extend outwards beyond the coast-line. It is, therefore, probable that the elevation was much greater than the minimum estimate given above.

On the other hand, there are some physiographical features that show that the land has been more deeply submerged than at present since these valleys were eroded. In many places along the coast-line old marine rock-shelves can be found. They are especially noticeable near Cape Saunders, at Sandy Mount, and at Sea View. The most distinct of them is about 250 feet above the present sea-level. At Sandy Mount the change of sea-level has been responsible for the formation of the magnificent natural bridge. The span of the bridge is 250 feet above sea-level and 30 feet wide. Its surface is level with the old marine plain or shelf. The ravine that it spans follows the course of a tinguaite-dyke. When the land-level was 250 feet lower, marine erosion worked the coast-line back 100 yards farther than the present sea-margin, and this old sea-margin is now marked by a ridge of worn cliffs. As elevation proceeded the coast-line reached farther forward, but is now being worn back again, though with extreme slowness, because of the hardness of the rock.

Along the tinguaite-dyke, planes of rock-fracture have enabled the marine action to proceed with greater rapidity, and a ravine with vertical walls, except where landslips have sloped it off, has resulted. The erosion has been confined to the sea-level, and at the sea-margin, where the diameter of the dyke increases slightly upward, some of the tinguaite has been supported in place, and, constituting the arch of the natural bridge, thus prevents the sides of the ravine from slipping.

There are no marine shelves or other indications in this district tending to show that the submergence has ever been greater than 300 feet below its present level. The identity of level, between the inner and outer portions of the sand-flats at the entrances to the inlets, shows that the present level has been maintained for a long period of years.

All the exposed surface of the rocks has undergone much decomposition, and rich soils have been formed. On these soils, a sufficient rainfall and a mild climate have favoured the growth of a luxuriant forest-vegetation, extending to the water's edge. On some of the more exposed hill-tops, scrub and native grasses take the place of the forest, and on the flat summit of Swampy Hill a luxuriant growth of moss so efficiently retains the abundant rainfall, that an extensive peat-bog has been formed. During the last fifty years, the growth of primæval forest has been felled by the settlers, and the hillsides are now clothed with a dense sward of grass; but this hides the rock-outcrops almost as effectually as the original forest, and greatly increases the difficulty that must always be considerable in attempting to solve the intricate relations between the many kinds of igneous rocks found here.

II. Description of the Rock-Types, and their Geological Occurrence.

The rocks of the district belong to so many different types, and the alternations and transitions from one type to another are so frequent and abrupt, that much material will probably be discovered, which will be of importance in testing the various theories that have been advanced to account for the differences in structure and composition observed in igneous rocks in various regions.

Many difficulties are encountered when one attempts to define the range and extent of any lava-stream. In the first place, the thick covering of vegetation and depth of soil prevent, over a great part of the area, all possibility of obtaining specimens of the rock from which the soil has been formed. The boulders that sometimes occur on the surface are in many cases clearly not *in situ*, and examination of them is more likely to lead to erroneous than to correct conclusions.

Although microscopic methods show that many quite divergent rock-types are present, the differences between them are often by no means apparent in hand-specimens. Many of the rocks are so fine-grained and of so uniform a black, that much field-practice with these particular rocks is necessary before the different kinds can be distinguished with any certainty. Many of the basalts are so nearly identical in megascopic characters with some trachytoid phonolites, andesites, nephelinitoid phonolites, trachydolerites, and basanites, that field-observations and conclusions often prove to be entirely incorrect. The late Prof. G. F. H. Ulrich,[1] when writing of this district, said that the rock-varieties require

> 'for their identification both chemical and microscopical examination nearly step by step.'

On the other hand, there are many excellent sections exposed on the lengthy sea-coast, while the small streams have everywhere cut

[1] Rep. Austral. Assoc. Adv. Sci. vol. iii (1891) p. 146.

deep into the rocks, and thus the work is rendered less difficult; though the want of connexion between the sections is especially confusing in such a district as this, where changes so sudden and complete occur in places where the margin of one lava-sheet is reached, or a sudden unevenness of the surface over which it flowed causes it to dip unexpectedly beneath a totally-different rock. For these and other reasons, of which one is the comparatively-large extent of the district, the present paper must be regarded as preliminary, although it is thought that the observations already made enable the general structure of the district to be correctly described, despite the fact that the details of nearly all portions are quite inadequately known.

Sixteen distinct rocks were described by the late Prof. Ulrich.[1] All the rocks that he examined were classed as phonolites and andesites, though he remarked that some varied toward tephrites and basanites. Many of these I have classed as trachydolerites.

Rock-specimens have been collected in fair number from portions of the district, and from these over a thousand microscopic sections have been prepared. The following classes of rocks have been recognized:—

I. Metamorphic:

Mica-schist.

II. Sedimentary:

1. Kainozoic sandstones and limestones.
2. Conglomerate.
3. Recent alluvium.

III. Igneous:

1. Hornblende-foyaite.
2. Augite-diorite.
3. Tinguaite.
4. Ulrichite.
5. Hypabyssal trachydolerite.
6. Camptonite.
7. Teschenite.
8. Trachyte.
9. Kaiwekite.
10. Trachytoid phonolite.
11. Nephelinitoid phonolite.
12. Leucitophyre.
13. Trachydolerite.
14. Andesite.
15. Nepheline-basanite.
16. Dolerite, Mount-Charles type. Dolerite, Papanui type.
17. Basalt.
18. Melilite-basanite.
19. Port-Chalmers breccia.

Metamorphic rocks.—The age of the mica-schist is not definitely known. By the late Capt. Hutton it is, on general grounds, referred to the pre-Cambrian Era. By Sir James Hector—whose opinion is chiefly based on the petrographic similarity of the schist to certain rocks the position of which is definitely known in the Nelson province—the mica-schist is referred to the Silurian Period.

Whatever its true age, the complete metamorphic nature of the rock without steep or complicated folds, and its entire unconformity to all other formations of the district, prove that it has been very deeply buried. Its emergence at the surface is the result of

[1] Rep. Austral. Assoc. Adv. Sci. vol. iii (1891) pp. 127–50.

the formation of an extensive anticlinorium and consequent prolonged denudation.

The rock occurs on the western outskirts of the present district, and fragments are frequent in the Port-Chalmers Breccia. Elsewhere it extends for 100 miles to the west and 50 miles to the north and south of the district, in unbroken continuity except when fringed on the margin by Tertiary formations, or where river-valleys or basins have been wholly or partly filled by late Tertiary or recent accumulations of gravel or other alluvium.

Where the schist is in contact with other rocks of this district, it has a fairly-uniform dip of about 30° in a direction S. 40° E.

Kainozoic calcareous sandstone.—In hand-specimens this rock is of a light grey colour, quite fine-grained. Sections show a number of tests of foraminifera, among which forms like *Textularia*, *Cristellaria*, and *Globigerina* can be distinguished. The sand-grains are subangular, and consist solely of quartz.

The Tertiary sandstones and limestones have a thickness of about 1000 feet at Whare Flat, where the schist is exposed below them and the basalt of Swampy Hill is to be seen above them.

The main part of the formation is a white calcareous sandstone, which forms vertical marine cliffs at Sea View and at Seacliff, in the southern and northern part of the district respectively. It has, in these two localities, a slight dip (5 to 10°) westward. Near Brighton, where the Tertiary deposits rest upon the mica-schist, the base of the formation is a clean white quartz-sand, upon which rests a seam of inferior brown coal. This is covered by a fine conglomerate, consisting of pebbles of quartz evidently derived from the schist. In the conglomerate are many fragments of shells of *Ostrea*, and abundant specimens of *Actinocamax*, a late form of belemnite. The conglomerate is succeeded by the calcareous sandstone previously mentioned, and this is again covered by white and green sands, the latter containing sharks' teeth and *Waldheimia*.

The Tertiary formations are not found above the sea-level in most parts of the district, but they rise in Swampy Hill to a height of 1700 feet above sea-level. In Mornington there is a pit whence the upper white sand is obtained, 500 feet above sea-level. In the Glen quarry at Caversham, half a mile distant, the same deposit is found 30 feet above sea-level.

On the Otago Peninsula there is an outlier of the calcareous sandstone at the Sandymount schoolhouse. Here it dips 30° southwestward at 560 feet above sea-level, although it is nowhere exposed at the neighbouring sea-margin except on the opposite side of Hooper's Inlet, where the dip is in the same direction, but steeper. On the opposite side of Otago Harbour, a small outcrop at Blanket Bay dips 20° north-westward, and another in Dowling Bay 40° north-north-westward.

These facts show that the Tertiary formations have at present a highly-irregular surface. It is probable that this irregularity was chiefly caused by erosion before volcanic activity commenced.

although in places local disturbances of these strata undoubtedly took place during the eruptions.

The seams of brown coal that are found in the Tertiary formations occur usually near the base, and rest, with few underlying strata, upon the schist. Some of them, at Saddle Hill and in the valley of the Kaikorai stream, are extensively worked.

The fossils found in the calcareous sandstone-series are sufficient to allow of the correlation of this formation with contemporaneous strata in other parts of New Zealand. There are numerous foraminifera—species of *Nodosaria*, *Textularia*, *Cristellaria*, and *Lagena*, but none have so far been described. Of mollusca, *Pecten Huttoni* is abundant and characteristic. *Waldheimia lenticularis* is the most abundant brachiopod; and *Meoma Crawfordi* an echinoderm. These are sufficient to class the formation as belonging to the Oamaru System (of Oligocene age) of Hutton's classification, and with the Cretaceo-Tertiary of the New Zealand Geological Survey.

In a few localities, notably in the Kaikorai stream on the north-east side of Swampy Hill, and at Waikouaiti, fine shales rest upon the calcareous sandstone-rocks. They are, in the former place, unconformable to the marine beds below them, probably unconformable in the second locality, and Prof. James Park has described them as unconformable at Waikouaiti.

The leaves are in a good state of preservation. A collection has been placed in the hands of Mr. Deane, of Sydney, who has done so much excellent work on the Tertiary flora of Australia. A preliminary examination of them tended to show that, although there was present an important element similar to the recent flora of New Zealand, there was also another element quite different from it. Prof. Park, without any identification, and relying entirely upon stratigraphical evidence in the Waikouaiti section, places the plant-beds in the Pliocene Period. Until Mr. Deane has completed his work, it is unwise to make any more definite statement than the vague assertion that the leaf-beds are of post-Oligocene age.

At the Swampy-Hill locality the plant-shales are highly carbonaceous, and contain a considerable quantity of paraffin.

At the Swampy-Hill and Waikouaiti localities, a pumice or light scoria-bed rests upon the leaf-beds; and in all the three leaf-bed localities, and in many others, there are beds of gravel or conglomerate lying upon the leaf-beds where present, or otherwise upon other Oligocene formations or upon some lava-flows, and they are in their turn covered by other lavas.

The Kaikorai valley (Frazer's Gully) is again the most important locality for the study of this formation, for the conglomerate is here 100 feet thick, extends over many acres, and is intersected throughout by the gorge of a small stream. In this locality it is conformable to the underlying leaf-beds, and is probably so at Waikouaiti and Swampy Hill. In all cases where such a conglomerate has been found, it is composed of fragments of volcanic

rocks; and the examination and classification of these furnish a considerable aid in fixing the relative ages of some of the different rock-types. Their consideration will be left over, until the discussion of the various rock-types to which the boulders belong. Wherever these conglomerates have been observed, they are covered by sheets of lava, usually of a basic character.

Alluvium of recent accumulation fills the lower portion of many of the stream-valleys. It consists usually of gravel. Its presence is of little interest or importance, except as showing that some depression has taken place since the valleys were eroded.

Blown sand is found in all the sheltered bays round the coast. The sand is first deposited on the beach, whence it is blown until its further course is arrested by the growth of vegetation or by the opposition of some rock-mass. The sand has been deposited in greatest quantity on the northern and north-western sides of the inlets, especially those larger ones that have prominent projecting south-eastern points.

In most instances the rapid growth of vegetation has prevented the sand from blowing on to the adjacent hill-slopes. At Sandfly Bay and at Rauone Beach, near Taiaroa Head, the growth has not been sufficiently rapid to prevent this movement, and the sand has been blown over a saddle 800 feet high at Sandy Mount and 400 feet high at Rauone.

This sand is formed almost exclusively of quartz-grains. In localities where the prevalent south-westerly and north-easterly winds have full play, the backward and forward movement of the sand has produced dreikanter with a sharp summit-ridge directed from north-west to south-east.

Igneous Rocks.

1. Hornblende-foyaite.—The only rock classed under this head occurs apparently as a massive intrusion, at the base of the Harbour Cone near the shore of Hooper's Inlet. It is a light-grey type, showing felspars and amphibole in the hand-specimen, with some pyrite which is most frequent round the border of the hornblende-crystals.

In section, the rock shows an allotriomorphic structure. Some of the felspar is orthoclase and part oligoclase-andesine, twinned after the albite and sometimes after the pericline-law. A little nepheline, much decomposed, is also present. The hornblende is dark brown, with the pleochroism of arfvedsonite. It is surrounded by a broad resorption-ring, consisting of ægirine-augite in very fine grains, magnetite, and pyrite. The hornblende is penetrated by numerous, short, stout prisms of apatite. (See Pl. XXXVII, fig. 1.)

Chemically, this rock agrees closely with foyaites from other localities, as the following analyses demonstrate:—

	A.	B.	C.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	53·54	56·71	53·09
Al_2O_3	22·52	22·49	21·16
Fe_2O_3	3·50	3·40	1·89
FeO			2·04
CaO	3·01	2·22	3·30
MgO	0·43	1·19	0·32
Na_2O	8·80	7·37	6·86
K_2O	5·26	5·87	8·42
P_2O_5	0·34	...	0·15
H_2O	3·30	0·45	3·28 *
Totals	100·70	99·70	100·51

* This includes CO_2, TiO_2, ZrO_2, SO_3, Cl_2, S, MnO, and BaO.

A = Hornblende-foyaite, Harbour Cone, Dunedin. Anal. D. B. Waters.
B = Foyaite, Bratholmen (Southern Norway). Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 129, No. 2.
C = Foyaite, Diamond Jo Quarry, Magnet Cave. Journ. Geol. Chicago, vol. ix (1901) p. 645; anal. H. S. Washington.

The close agreement of these analyses supports the classification of the rock as foyaite, which was based on the mineralogical composition. The matter has been fully discussed by Mr. C. N. Boult, in a paper that is now being published by the New Zealand Institute.

Several other varieties of nepheline-syenite are represented in the Port-Chalmers Breccia. They vary considerably, but as all the fragments are small—not more than 20 centimetres in diameter—it is inadvisable to attempt a classification of them, as none of them is necessarily typical of the rock-mass from which they are derived. In all cases they contain much felspar—always orthoclase—and its structure usually is completely allotriomorphic. Nepheline is present in some quantity, but is considerably decomposed. It seldom shows any crystallographic boundaries. Ægirine is the most frequent dark constituent. It is of a very bright green, with an extinction-angle of 15°. It is intensely pleochroic, and has the usual formula —𝔞 deep green, 𝔟 yellowish green, 𝔠 dirty yellow. One crystal is cut almost at right angles to an optic axis, and indicates a strong inclined dispersion of the bisectrices. In several slices a biotite is associated with the ægirine. It is intensely pleochroic—𝔟 and 𝔠 dark brown, 𝔞 bright golden-yellow. No hornblende or other coloured constituent is present, except in one slice a core of brown augite closely surrounded by golden mica and ægirine. Some of the mica-plates are crowded with apatite-inclusions, when the mineral closely resembles the crystal of pseudobrookite illustrated by Prof. Brögger,[1] if it be cut nearly parallel to the base, and fails to show the pleochroism that is so noticeable in all other sections. This golden mica is not found in any of the volcanic rocks of the district, although some of the phonolites must be their volcanic equivalents. The absence of amphibole and sodalite in these plutonic

[1] 'Die Eruptivgesteine des Kristianiagebietes: I—Die Gesteine der Grorudit-Tinguait-Serie' Christiania, 1894, p. 44 & pl. ii, fig. 1.

fragments is striking, when considered in reference to the mineralogical composition of the phonolites. No chemical analysis of these rocks has been made, but a crystal of ægirine was analysed with the following result:—

	A.	B.
	Per cent.	*Per cent.*
SiO_2	49·10	51·60
Al_2O_3	1·46	1·92
Fe_2O_3	25·14	26·29
FeO	9·26	4·20
CaO	2·95	4·25
MgO	0·13	1·15
Na_2O	8·11	8·89
K_2O	1·79	1·05
Totals	97·94	99·35

A = Inclusion in breccia, Port Chalmers (N.Z.); anal. P. Marshall.
B = Ægirine in elæolite-syenite, Barreros, Serra dos Poços de Caldas, São Paulo (Brazil); Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 125, No. 10.

The result (A) which was obtained from the examination of a very small quantity of material, shows that the mineral is a typical ægirine.

The foyaite has only been discovered *in situ* at the spot already mentioned, at the eastern base of Harbour Cone, near the shore of Hooper's Inlet. It does not crop out at the surface, but was exposed near the bottom of a shaft sunk to prospect for gold-mining. The rock carries a certain amount of gold, varying from 2 to 14 dwt. per ton. The methods employed for saving the gold were not efficient enough to make the venture a paying one.

This rock was classed by Ulrich as a

'trachyte-greenstone, though hardly distinguishable from the quartzose-diorite greenstone of some of the dykes which in Victoria traverse Upper Silurian rocks.' [1]

Prof. Park describes the rock as

'a hornblende-andesite, although it is probably more closely allied to porphyritic diorites.' [2]

The reasons for its classification as a foyaite have been given above. Although this rock has practically no outcrop, its lateral extension is probably considerable, for fragments of it are frequently met with in the Port-Chalmers Breccia.

Other syenites are found rather frequently as fragments in the breccia. Some of these are described in the preceding notes on the petrography, and it will be seen that in them the amphibole is replaced by ægirine, which is in some specimens present in large crystals. None of these nepheline-syenites with ægirine have been discovered *in situ*.

[1] Hutton & Ulrich, 'Geology of Otago' 1875, p. 167.
[2] N.Z. Geol. Surv. Reports, 1888–89, p. 35.

2. Augite-Diorite.—Macroscopically, the rock is of a fresh-looking light-grey type, penetrated by narrow bands of darker colour. The bands are 1 centimetre thick and 7 cm. apart.

In slices, the rock is found to consist almost entirely of triclinic felspar, the extinction-angle of which is that of andesine; the structure is panidiomorphic. Small grains of a very pale augite and crystals of magnetite are frequent. A violet-brown perofskite in crystals, sometimes measuring 1 millimetre in diameter, is also frequent. The occurrence of the titanium-mineral perofskite is particularly noticeable, because no sphene has been found in any rocks of the district, and the only other titaniferous mineral that occurs is cossyrite.

The large rock-mass placed in this class occurs almost in the middle of the city of Dunedin, forming the Bell Hill. The diorite clearly underlies all the volcanic rocks near it, and in the road-cutting in Dowling Street it is seen that the diorite-surface was eroded, uneven, and much decomposed, before the overlying andesite flowed over it. The diorite is so much decomposed, indeed, as to resemble a sandstone in all those portions which are near its surface. The unaltered rock is exposed in the face of the Bell Hill where, prior to the accumulation of sand and to European colonization with its consequent reclamation, marine erosion had removed all the weathered portion. A very prominent spheroidal weathering is to be seen, and its dark horizontal bands seem to indicate that the rock has yielded to pressure and become crushed along these planes.

Except in the Bell Hill and its neighbourhood, this rock is nowhere exposed, and no fragments have been found in the breccia at Port Chalmers.

3. Tinguaite.—Rocks that are classified under this division occur quite frequently. Among them are fifteen well-defined dykes of a compact light-green rock, which differs but little from ordinary tinguaites. There are others that are coarsely porphyritic, and one that is distinctly camptonitic in structure.

In thin slices some examples (Hooper's Inlet and Acheron Point) show crystals of dark-brown hornblende with the pleochroism of basaltic hornblende. It is always fringed with ægirine. The needles of ægirine vary in size, but are never large. Felspar is almost entirely absent in crystals and microliths; an exception is found in the rock at Acheron Point, in which small crystals of sanidine (twinned on the Carlsbad law) are not infrequent. Nepheline is occasionally present in rather corroded phenocrysts, but crystals are not distinguishable in the groundmass, which is quite isotropic between the ægirine-needles. In two examples (Fish-Hatcheries and Hooper's Inlet) a peculiar spherulitic structure appears in the groundmass. The mineral of which the spherulite is composed is highly birefringent—as strongly as quartz—and quite transparent. With ordinary light it is impossible to determine which part of a section is spherulitic. The spherulites between crossed nicols

show rather an irregular black cross, and the mineral of which they are composed is platy rather than fibrous in structure. I have been quite unable, with the means at my disposal, to identify the mineral or to satisfy myself as to whether it is original or secondary.

Only one of these numerous tinguaites has been analysed (A). Petrographically it is the most compact of all.

	A.	B.	C.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	56·17	54·46	52·40
Al_2O_3	19·25	19·96	19·93
Fe_2O_3	4·77	2·34	3·83
FeO	2·72	3·33	1·51
CaO	1·26	2·12	1·34
MgO	0·21	0·61	0·32
Na_2O	6·08	8·68	11·71
K_2O	4·66	2·76	4·10
P_2O_5	0·21	...	trace
H_2O	4·09	5·20	3·94
Totals	99·42	99·46	99·08

A = Dyke, Acheron Point, Otago Harbour (N.Z.). Anal. P. Marshall.
B = Tinguaite, Umptek, Kola. Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 223, No. 12.
C = Tinguaite, Mount Kosciuscko (N.S.W.). Anal. F. B. Guthrie, Journ. & Proc. Roy. Soc. N.S.W. vol. xxxv (1901) p. 366.

The analyses show the great similarity which the New Zealand rock bears to that from Russian Lapland, although it is less alkaline than that from New South Wales. The only other Australasian tinguaites of which I have heard occur at Cygnet Cove (Tasmania), but I am not aware that any analyses of these have been published. Their sections show a much greater development of felspar and, of course, much less isotropic matter.

A porphyritic type occurs at Sea View. Large crystals of nepheline, 1 centimetre in diameter, are frequent, and felspar-crystals (sanidine) of the same size are common. In thin slices, both of these minerals are seen to be idiomorphic. Small crystals of idiomorphic ægirine-augite are also present, and the groundmass is composed of a very fine-grained mixture of ægirine-augite, sanidine, magnetite, and a little brown hornblende (cossyrite). In some slices olivine and brown augite may be seen, but they are in small quantity. There is every variation in this locality between the porphyritic type with conspicuous nepheline-crystals and an extremely-dense green rock without any phenocrysts, and showing the same incipient spherulitic structure as that described in the Purakanui phonolite on p. 402.

Another porphyritic type forms a small dyke near Port Chalmers. The sanidine-crystals are here relatively smaller, and nepheline less frequent, but the groundmass is somewhat coarser.

Large boulders of another type occur in the breccia near the

wharf at Port Chalmers. In these felspar-phenocrysts are very numerous, and are in part anorthoclase. A little olivine is present, and there is much nepheline in the groundmass as well as in phenocrysts. Small crystals of ægirine frequently occur in the groundmass, and cossyrite is much more abundant than in the rock from Sea View. This type with a nephelinitoid groundmass has not been found anywhere *in situ*, nor has any analysis of it been made.

On the Peninsula there is a large intrusion of another, less strongly-porphyritic, type. The only phenocrysts are of nepheline, and they are comparatively small (2 mm.), but they are always idiomorphic. Ægirine, nepheline, and sanidine are present in abundance in the groundmass. The ægirine is very green, and shows an extinction-angle of 20°. There is no cossyrite or magnetite.

Still another comes from Papanui. The large felspars and nepheline-crystals embedded in a dark-green groundmass give the rock an appearance intermediate between the specimens from the breccia and that from the Peninsula.

A rock that has been used for the breastwork of the road round Hooper's Inlet is, in some respects, different from all of these. Felspar-phenocrysts are not infrequent, and felspar-microliths are the most important constituent of the groundmass. The nepheline is all in the groundmass and is not very abundant, but it is markedly less decomposed than the felspar. The coloured constituent is nearly all ægirine. It occurs in groups of crystals with magnetite and analcite, and in the middle of these groups there is often some hornblende. It is evident that the ægirine, magnetite, and analcite have been derived from hornblende-crystals. (See Pl. XXXVIII, fig. 1.) The change must have taken place after magmatic movements had ceased, for no indication of flow-structure has been observed.

A quantitative analysis yielded the following result:—

SiO_2	50·16
Al_2O_3	19·75
Fe_2O_3	4·28
FeO	3·62
CaO	3·10
MgO	1·12
Na_2O	7·63
K_2O	6·73
P_2O_5	0·13
H_2O	3·96
Total	100·48

This rock, from its mineralogical composition, must be classed as a tinguaite, although its silica-percentage is so low. The change of the amphibole to the minerals named was more a matter of magmatic resorption than of decomposition.

The last rock to be mentioned under this head occurs near the Purakanui railway-station. Phenocrysts of sanidine, nepheline, and sodalite are very frequent, and the groundmass is a mixture

of sanidine, nepheline, ægirine, and cossyrite, the last-named being rather abundant. The geological occurrence of this rock, coupled with its mineralogical composition, proves that it is a slowly-cooled equivalent of the Mopanui nephelinitoid phonolite to be described later (p. 404).

4. Camptonitic type of tinguaite (ulrichite).—This rock occurs at the end of the Portobello Peninsula. It was described by the late Prof. Ulrich as a porphyritic phonolite.[1] The nepheline-phenocrysts measure sometimes 2 centimetres in diameter, and the felspars 4 cm. Both are idiomorphic, and the latter are usually sanidine, but some are anorthoclase; they are very frequent. Occasionally large crystals of brown hornblende occur, and smaller ones of analcite, olivine, and ægirine: the first is certainly original, for it is penetrated by microliths of felspar. The olivine is sometimes idiomorphic, and the ægirine is always so. The groundmass consists of sanidine, hornblende, and ægirine. The extinction and pleochroism of the hornblende prove it to be barkevikite: it is often fringed with ægirine.

Chemically, the rock is not very different from several others that have been called tinguaites, as the following analyses show:—

	I. *Per cent.*	II. *Per cent.*
SiO_2	53·64	53·28
Al_2O_3	18·26	16·38
Fe_2O_3	4·66	6·11
FeO	2·72	4·52
CaO	3·70	3·09
MgO	1·53	2·50
Na_2O	5·51	6·42
K_2O	5·86	4·18
P_2O_5	0·12	0·15
H_2O	3·73	3·52
Totals	99·73	100·15

The two samples were taken from different parts of the same dyke. This seems to me a type widely different from a normal tinguaite; and I propose for it the name ulrichite, after the original discoverer of the alkaline rocks of Dunedin.

The dykes of tinguaite penetrate the rocks near Portobello and Port Chalmers in some number, and extend to the eastern coast between Sandfly Bay and Wickliffe Bay.

The tinguaite-dykes vary from 6 inches to 15 feet in width, and they appear to radiate from a point near Port Chalmers. The mass near the Limekilns on the Peninsula and the coarse type at Sea View are much larger masses; but their exact boundaries cannot be defined, because of surface-vegetation.

5. Hypabyssal trachydolerite.—The summit of Mount Flagstaff and part of its southern and western slopes consist of a

[1] Trans. Austral. Assoc. Adv. Sci. vol. iii, 1891 (Christchurch) p. 128.

porphyritic rock that appears to be intrusive. Olivine, augite, and nepheline are present as in the effusive type, but are in rather larger crystals. There are many big crystals of felspar: anorthoclase and sanidine. Sodalite is occasionally present in crystals of moderate size. The groundmass contains a large number of felspar-microliths, much ægirine, and some cossyrite and magnetite.

At Pine Hill another type of this rock occurs. Olivine is less abundant, and there is but little brown augite, but nepheline and felspar are abundant as phenocrysts. There are numbers of completely-resorbed crystals of hornblende, the form of which has not been lost. In the groundmass there is some dull-green ægirine-augite, no cossyrite, and a very fine-grained development of felspar and nepheline. I have made no analysis of either of these rocks.

There is no evidence of this trachydolerite overlying or being covered by any other of the rock-masses near it; and the sudden change from the coarse variety to the volcanic rocks around, suggests its intrusive nature. The summit of Flagstaff is one of the highest points of the whole district, and may well represent the volcanic pipe from which much volcanic material was emitted in the southern portion of the Dunedin volcanic area. At Pine Hill the rock-mass is much smaller, but it is as sharply separated from the surrounding rocks as is the occurrence at Mount Flagstaff.

6. Camptonite.—The rock here described is not a normal member of the group, although it shows closer affinities to it than to any other group of rocks. It is a light-grey rock, with large steam-cavities lined with analcite-crystals. In sections big phenocrysts of oligoclase are seen. There are smaller crystals of hornblende, and these are embedded in a groundmass of felspar, analcite, hornblende, and ægirine; (see Pl. XXXVIII, fig. 2 & Pl. XXXIX, fig. 1). The dyke is 15 feet wide, and juts out into Portobello Bay. The following quantitative analysis of the rock was obtained:—

SiO_2	51·48
Al_2O_3	16·37
Fe_2O_3	5·71
FeO	4·64
CaO	3·60
MgO	1·81
Na_2O	5·86
K_2O	4·09
P_2O_5	0·21
H_2O	5·82
Total	99·59

This camptonite evidently is closely related to the ulrichite described above, but differs from it in the presence of triclinic felspar, in the greater abundance of hornblende, and in the absence of nepheline and olivine.

A rock rather similar to this, but not so fresh, occurs in a dyke at Port Chalmers. Much calcite is found in it; there is also much less ægirine and more analcite.

The classification as camptonite is rather unsatisfactory, as the rock is more acid and contains more alkali than is usual. However, structure and mineralogical composition alike appear to justify this classification.

7. Teschenite.—The rock described here occurs as a small dyke penetrating the Port-Chalmers Breccia at Mussel Bay. Hand-specimens are black and dense. The thin slices show a mixture of labradorite and augite, displaying (but not very conspicuously) the violet pleochroism usual in these rocks. There are a few serpentine-pseudomorphs after olivine. Analcite is rather frequent in large rounded grains, showing the typical cleavage, and is almost certainly primary. Round the analcite are some narrow prisms of hornblende and sanidine-microliths. These form small complexes exactly similar to portions of the camptonites described above. They seem to be xenoliths of camptonites that have been included in a basic magma, rather than original secretions from the magma.

8. Trachyte.—This rock consists almost wholly of felspar. In hand-specimens it is white, and glassy crystals of sanidine almost rectangular in shape can often be distinguished in it.

In thin slices no coloured constituent can be seen in specimens from most of the localities. Felspar-microliths exhibiting flow-structure, with a few felspar-phenocrysts, constitute the whole mass of the rock. In most cases the felspar does not show the microscopic structure of anorthoclase; it is therefore ascribed to sanidine. In some examples (Hooper's Inlet) the rock has small grains of magnetite. In one example (Omihi) much of the felspar is anorthoclase, and there is some ægirine-augite. The rock weathers readily, and is often stained red by infiltrated iron-salts.

As would be expected from the mineralogical composition of this rock, analysis shows that a very small quantity of iron, calcium, and magnesium is present:—

	A.	B.	C.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	66·04	66·50	66·20
TiO_2	...	0·70	...
Al_2O_3	18·38	16·25	19·86
Fe_2O_3	1·05	2·04	1·03
FeO	...	0·19	...
MnO	...	0·20	...
CaO	0·96	0·85	0·80
MgO	0·69	0·18	0·17
Na_2O	7·22	7·52	7·45
K_2O	5·09	5·53	4·10
H_2O	1·50	·50	...
Totals	100·93	100·46	99·61

A = Trachyte from Portobello, Dunedin (N.Z.). Anal. P. Marshall.
B = Lestiwarite from Kvelle. 'Die Eruptivgesteine des Kristianiagebietes III — Das Ganggefolge des Laurdalits' Christiania, 1898, p. 235. Anal. W. C. Brögger.
C = Anorthoclase from Rakhalè. Anal. Förstner, quoted by Dana, 'System of Mineralogy' 6th ed. (1892) p. 324.

The remarkable similarity of analyses A & B shows that the rocks are almost identical. The lestiwarite, however, is a dyke-rock, whereas the trachyte is for the most part a lava-flow, although dykes that differ in no respect from the lava are found. It is interesting to compare these analyses with that of anorthoclase placed beside them. The very great similarity is remarkable, and is perhaps sufficient in itself to justify us in regarding the Portobello trachyte as really an anorthoclase-rock.

Trachyte is found over a considerable area around the Quarantine Islands. It is usually associated with scoriaceous formations, and often shows a conspicuous flow-structure: therefore, it was undoubtedly a lava in most of its occurrences. At times it is porphyritic, with large crystals of anorthoclase embedded in the fine white base: more usually it is fine-grained. The large crystals can be detached from the decomposed base in places. They are bounded by planes inclined almost at right angles, but they have not yet been accurately measured with a reflecting-goniometer. At two places on the Portobello Peninsula this trachyte forms dykes that penetrate the coarse Mount-Charles Dolerite which forms the main mass of the peninsula. The contrast between the white and the black rocks is very striking. The trachyte is pierced by tinguaite- and camptonite-dykes at Portobello, as well as by basaltic dykes at Portobello and Omihi, and no dykes of trachyte have been observed traversing any rocks except the Mount-Charles Dolerite. The trachyte-lavas underlie basalts, trachytoid phonolites, and all the other lavas described, except the Mount-Charles Dolerite. The trachyte was, therefore, evidently emitted after the dolerite in question, and before any of the other lavas of the district.

9. Kaiwekite.—Hand-specimens are of a dull-green colour, and show numerous bright cleavage-planes of large felspar-crystals, which have the same dark coloration as that which is so noticeable in the Norwegian rhomb-porphyries. Slices show that the phenocrysts are composed of anorthoclase (see Pl. XXXIX, fig. 2), and contain numerous inclusions of glass, ægirine-augite, and other substances. Smaller crystals of ægirine-augite are frequent, and there are occasional serpentine-pseudomorphs after olivine. Many of the smaller felspar-crystals are almost perfect squares, and they are embedded in a groundmass of felspar-laths and grains of ægirine-augite. I have been unable to distinguish nepheline in the slices or by staining methods, although treatment of the rock-powder with acid and subsequent evaporation produce numerous crystals of sodium-chloride.

In some examples of this rock (Long Beach and Wickliffe Bay) there is much triclinic felspar (oligoclase), but it is always bordered by untwinned mineral. In the same examples, irregular grains of pale-brown augite are common; they always have a margin of ægirine-augite, containing many grains of magnetite. The ægirine-augite fills up the irregularities of the crystal, and gives it a sharp idiomorphic outline. Brown hornblende is occasionally present (Long Beach), of tenin large crystals, 5 centimetres long.

This rock was at first classed as a rhomb-porphyry, but specimens sent to Prof. Rosenbusch and kindly examined by him, led him to inform me that it would be unwise to use this name in the absence of the characteristic rhomboidal shape of the felspar-phenocrysts. However, he agrees that the rock is a perfect mineralogical equivalent of these rocks, and is the effusive representative of the plutonic laurvigites. I have not made any chemical examination of the rocks of this class, but suggest the name of kaiwekite, after the native name of the Long-Beach locality, Kaiweke.

Perhaps the most prominent characteristics of the kaiwekites, variable as they are in appearance, are as follows:—(1) The abundance of anorthoclase and various felspathic intergrowths; (2) the very frequent square and isometric sections of felspars in the groundmass (see Pl. XXXIX, fig. 2); (3) the comparative absence of coloured rock-forming minerals; and (4) the frequent occurrence of pyroxene, with a brown centre and an ægirine-margin, and of serpentine-pseudomorphs after olivine.

In the accompanying geological map (Pl. XXXVI) the kaiwekites are not specially indicated. They are omitted, because they usually occur as boulders in localities where there are no means of gaining any knowledge as to the relations of the kaiwekite to neighbouring rock-masses. In general it would appear to be intrusive, but at Long Beach it forms a great lava-flow constituting a prominent cliff on the west side of the Bay; and at Wickliffe Bay there is another lava-flow forming a similar cliff on the north side of the Bay.

10. Trachytoid phonolites.—The variety of these rocks is very great. They all have an extremely-dense texture and a dark-green colour. In many, no phenocrysts whatever can be distinguished. I have found it advisable to divide them into four types.

(A) Logan's-Point type.—Extremely dense. The rock is a dense web of felspar-microliths, and in the meshes are nepheline-crystals, ægirine, and cossyrite. The nepheline is hard to distinguish without staining, but after staining it is seen to be a highly-important constituent. It is idiomorphic, while the ægirine and cossyrite are allotriomorphic. The last-named is extremely pleochroic, though in greenish-brown tints. It has a remarkable spongy texture, but all the portions of one of the spongy growths, though often separated by felspar-crystals or nepheline, have a uniform extinction.

(B) St. Leonard's type.—Phenocrysts of brown hornblende are common, as also occasional phenocrysts of felspar (anorthoclase and oligoclase). The groundmass is a dense growth of felspar-microliths and small grains of ægirine-augite. It is hard to detect nepheline; but, after staining, this mineral is found to occupy much of the space between the felspars and the ægirine-augite grains. The nepheline is allotriomorphic. There is no cossyrite in this rock.

(C) Andesitic type.—Very dense. Felspar-microliths show marked flow-structure, but do not constitute a web-like mass as in type A. There are a few phenocrysts of oligoclase. The ægirine-

augite is very pale. Nepheline cannot be distinguished, but when it is treated with dilute hydrochloric acid a large portion at once dissolves, and it contains a considerable percentage of alkali, as stated below. The evaporated solution deposits a great number of crystals of sodium-chloride. Staining does not take place readily, but with careful treatment a large portion of the groundmass becomes coloured. Its arrangement shows that the nepheline is allotriomorphic, and is in very small grains.

(D) Green phonolite.—Small crystals of brown augite, fringed with a bright-green border of ægirine. Smaller crystals of sodalite, sharply idiomorphic. Minute microliths of felspar, with ægirine-granules, in the groundmass. Sometimes the felspar shows a feeble spherulitic structure. There is some transparent glassy base, which probably is strongly alkaline. Evidently this rock is closely related to the Mopanui type of nephelinitoid phonolite. It occurs in a neighbouring locality. There is no cossyrite present, but there are occasionally crystals of nepheline. This rock is in all respects (except for the presence of sodalite) exactly similar to the green rock that I consider to be a marginal, rapidly-cooled portion of the alkaline intrusion at Sea View.

	A.	B.	C.	D.	E.	F.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	60·00	57·42	57·00	55·66	54·52	53·56
Al_2O_3	16·26	18·83	18·56	17·18	15·84	15·28
Fe_2O_3......	5·72	4·89	4·58	4·43	6·42	7·36
FeO	3·52	3·56	2·76	3·56	4·53	5·42
CaO	3·30	1·75	1·05	1·14	4·20	4·30
MgO	1·05	0·59	0·41	0·73	0·98	1·29
Na_2O	4·08	6·23	6·34	7·02	4·38	5·51
K_2O	4·17	5·46	6·13	5·30	4·23	4·88
H_2O	2·64	2·36	2·96	4·53	3·64	3·12
Totals	100·74	101·09	99·79	99·55	98·74	100·72

A = Trachytoid phonolite, Au Koraki.
B = Trachytoid phonolite, Signal Hill.
C = Trachytoid phonolite, Logan's Point.
D = Green phonolite, Purakanui.
E = Trachytoid phonolite, See House.
F = Trachytoid phonolite, See House.

Dunedin (N.Z.). Anal. P. Marshall.

Chemically there is a moderately-close relationship between all these rocks, although those with easily-detected nepheline are markedly more alkaline than the others. The high percentage of iron-oxides is characteristic of the whole group, as developed in Dunedin. The rock from Au Koraki (A) contains very little nepheline, but a large quantity of felspar, much of which is distinctly anorthoclase. This rock appears to be a connecting-link between the trachytoid phonolites and the trachytes. The green glassy type (D) is evidently closely related to the nephelinitoid type from Mopanui. This rock has some chlorine, but the amount was not estimated. The lava-flows at the See House (E and F) are different in texture, but they represent a very common type (andesitic) in this district. They

evidently connect this group with the andesites. An estimation was made of the amount of material dissolved from these rocks, when the fine powder was just brought to the boiling-point in dilute hydrochloric acid. Altogether 29·98 per cent. of the rock went into solution. An estimation of the substances in solution gave the following result:—

SiO_2	15·31
Al_2O_3	5·21
Fe_2O_3	3·54
CaO	1·24
Na_2O	1·53
K_2O	0·51
H_2O	2·64

The silica was chiefly in a gelatinous condition, and had to be dissolved in potassium-hydrate before estimation. This result shows that there is an alkaline silicate present that is decomposed by dilute acid. It is reasonable to suppose that this silicate is nepheline—a result that is borne out by staining.

There is a very large variety of these rocks in this petrological province. They crown the tops of many of the hills, and occur as interbedded sheets in several of the cliff-exposures.

With the exception of the green phonolite, the boundaries of the different types are not distinguished in the geological map (Pl. XXXVI) attached to this paper; but the following statement gives an idea of their relative position and abundance.

(A) Signal-Hill type.—Forms the main mass of Signal Hill and one of the small peaks of Mount Cargill. A continuation of the Signal-Hill outflow occurs on the south-eastern side of Otago Harbour, where it rests upon a dolerite. At Otago North Head a lava-flow rests on basalt, but is overlain by basanite and other basalts. The Signal-Hill rock rests upon basalt at the cemetery, and is overlain by basalt on the Junction Road and at the summit of the hill.

The emission of this lava was preceded by basalts which rest, to a depth of 100 feet, upon trachyte at North Otago Head.

Prof. T. W. Edgeworth David, F.R.S., in conversation has compared this rock with the phonolite of the Warrumbungle Mountains (New South Wales).

(B) St. Leonard's type.—No lava-flow of this has been discovered, except at the North Otago Head. Boulders of the rock are found in breccias, especially at Port Chalmers, and at North and South Otago Heads.

(C) Andesitic type.—By far the most general, forming the greater part of the northern portion of the high land of Otago Peninsula, the greater part of Roslyn and Maori Hill, and extending from the Junction Road on Mount Cargill with little interruption to North Otago Head.

The rock rests upon andesite at the Paper-Mills, and is covered by basalt. In most localities there is no basalt-covering, and this phonolite seems to be the latest lava emitted over the greater part of the district.

(D) Green phonolite.—In hand-specimens this rock has all the appearance of a tinguaite, but it forms a massive lava-flow 300 feet thick, extending from Blueskin Cliff almost to the summit of Mopanui. No section has yet been found that indicates the relation of this rock to others above or below it, although its field-occurrence shows that it is one of the latest products of eruption; and this conclusion is supported by its apparent relationship to the trachydolerite, which is itself one of the youngest of the rocks of this district.

11. Nephelinitoid phonolites.—From a large quarry at Normanby comes a type that contains a good deal of felspar, although its amount is less than that of the nepheline. The rock is fine-grained, and in addition to these minerals contains only ægirine and a little magnetite. Coarser examples of a similar rock occur at Signal Hill and elsewhere. One of the most interesting rocks of the district occurs at the top of Mopanui. In it very fine-grained nepheline is the most abundant mineral, and with this are occasionally seen minute laths of felspar, apparently sanidine. Crystals of sodalite are not uncommon; they are often extended in the direction of a dodecahedral axis. The coloured constituents are ægirine and cossyrite, in about equal proportions. The cossyrite is in small spongy growths, enclosing crystals of nepheline in its meshes: its pleochroism is from pale pink to reddish brown, and its arrangement is very similar to that in the rock from Kamnye River so well figured by Dr. Prior.[1] Prof. Rosenbusch was good enough to examine a slice sent to him, and he compares the cossyrite to the development of that mineral in the rock known as apachite. A few bigger crystals of brown augite fringed with ægirine are seen, and very rarely a small olivine fringed in the same way.

One of the peaks forming the summit of Mount Cargill is built up of a rock that does not differ very widely from that of Mopanui. There is less cossyrite, more sodalite, and less brown augite, but the fine-grained nephelinitoid base is very similar in the two rocks.

Chemically, the Mopanui rock—the only one analysed—is characterized by a high percentage of iron. The chlorine was not estimated, although qualitative tests showed that a considerable amount was present. The analysis agrees rather well with the other one quoted from Equatorial East Africa. Mineralogically, the latter rock appears to contain much more felspar, and nepheline is present in small crystals but not in the groundmass. I am unable to make a comparison with those African types which have nepheline in the groundmass, as there is no analysis in the literature at my disposal.

[1] Min. Mag. vol. xiii (1903) pl. v, fig. 4.

	A.	B.
	Per cent.	*Per cent.*
SiO_2	56·40	58·37
Al_2O_3	15·84	16·65
Fe_2O_3	6·48	4·09
FeO	3·54	3·03
MgO	0·21	0·37
CaO	1·52	1·66
Na_2O	5·80	7·28
K_2O	5·78	5·46
P_2O_5	0·13	0·08
H_2O	3·96	2·36
Totals	99·66	99·35

A = Nephelinitoid phonolite, Mopanui, Dunedin (N.Z.). Anal. P. Marshall.
B = Phonolite, Mount Kenya. G. T. Prior, Min. Mag. vol. xiii (1903) p. 240.

Except at Mopanui and Normanby, the nephelinitoid phonolites do not form large rock-masses. In all the localities in which they occur, it is difficult to distinguish the boundaries of the area covered by the rock, because of the growth of vegetation and the depth of soil that covers the ground around the outcrop.

12. Leucitophyre.—I have found a specimen of this type in one locality only, Puketeraki. It is a dark-green dense rock, showing on its fractured surface a slight shimmer, due to the large quantity of minute felspars. In slices the felspar is very abundant; the larger crystals are anorthoclase. The nepheline is in small quantity. Leucite occurs in the finer-grained types only. The crystals are almost round, and have concentrically-arranged, minute, needle-shaped microliths of ægirine. The leucites are not sensibly birefringent. The coloured constituent is a pale-green ægirine-augite, with much magnetite. The minute felspar-laths have an arrangement not very different from their web-like arrangement in the trachytoid phonolite of the Logan's-Point type (see p. 401).

	A.	B.
	Per cent.	*Per cent.*
SiO_2	52·88	48·95
Al_2O_3	14·44	18·43
Fe_2O_3	6·72	...
FeO	4·56	8·19
CaO	3·80	6·42
MgO	1·68	1·43
Na_2O	4·78	6·51
K_2O	7·09	6·90
P_2O_5	0·11	...
H_2O	4·00	1·79
Totals	100·06	98·62

A = Leucitophyre, Puketeraki, Dunedin (N.Z.). Anal. P. Marshall.
B = Leucitophyre (nosean-melanite rock), Perlenkopf, Olbrück. Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 292, No. 15.

Chemically, the silica-percentage is low and the iron-percentage high—a feature that recurs frequently in the Dunedin rocks. The

amount of alumina is correspondingly reduced. This must be due to the considerable quantity of magnetite that is present. The high percentage of lime in B is accounted for by the presence of melanite and nosean.

A plutonic inclusion occurs in several places in this leucitophyre (A). Slices show that it is composed almost solely of a glassy felspar (apparently orthoclase) and ægirine, the latter in small quantity. No nepheline or leucite were found in any of the slices.

The leucitophyre occurs only at Puketeraki, so far as known at present. In hand-specimens it differs but little from the ordinary trachytoid phonolites, and the leucite is but poorly developed. From surface-indications, the rock would appear to cover a considerable area near Seacliff, but this inference has not yet been confirmed by microscopical or chemical work.

The rock rests upon a melilite-basalt, which in turn overlies calcareous sandstone. The trachytoid phonolite forms the uppermost rock-formation of this part of the district.

13. Trachydolerites.—Dense dark-green or black rocks, in which crystals of olivine and nepheline can be distinguished. I have given a full description of these rocks elsewhere. In slices, olivine and brown augite are seen to occur in small grains, singly or in groups. In all cases they are surrounded by a mantle of ægirine and magnetite. Crystals of sodalite sometimes 5 millimetres long, but usually much smaller, are often present. Resorbed crystals of amphibole are often numerous (Mount Cargill) and sometimes a brown unchanged core remains. The groundmass has ægirine and cossyrite as coloured constituents. The latter always has a 'spongy' structure. Its pleochroism is intense, from pale greenish-brown to dark coffee-brown; but the absence of crystallographic outlines interferes with a determination of the pleochroic values of the different crystallographic directions. Sometimes there is a trachytoid, sometimes—though rarely—a nephelinitoid (southern slopes of Flagstaff) structure in the groundmass, which consists of varying proportions of these constituents. A little apatite is present. The rock varies but slightly throughout the 10 square miles of its extent.

An included fragment of a plutonic rock, found on the southern slopes of Flagstaff, was given to me by Mr. T. Menzies. It consists of sodalite, felspar (orthoclase), nepheline, a little cossyrite, and magnetite. The rock is hypidiomorphic. The pleochroism of the cossyrite is $\mathfrak{a}$ light-green, $\mathfrak{b}$ black, $\mathfrak{c}$ dark-brown. Extinction-angle on 010, 43°. There is no olivine or brown augite.

I have previously given an account of the chemical relationship of this rock in the 'Transactions' of the Australasian Association for the Advancement of Science, vol. x, 1904 (Dunedin) p. 186.

The analysis is repeated here (C):—

	A.	B.	C.
SiO_2	53·12	53·80	51·86
TiO_2	0·25	0·31	—
Al_2O_3...........	20·48	18·46	19·87
Fe_2O_3...........	5·13	6·22	6·30
FeO	1·50	0·40	3·11
CaO	4·29	2·53	3·77
MgO	1·88	1·05	2·33
Na_2O	6·20	7·09	4·88
K_2O	4·88	5·46	6·20
H_2O	2·25	4·39	1·48
Cl_2	0·28	MnO 0·33	Cl_2 0·51
P_2O_5	0·43	0·53	0·36
Totals......	100·69	100·57	100·67

A = Trachydolerite (tephritic trachyte), Columbretes (Spain). Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 355, No. 3 *a*.
B = Kenyte, from Mount Höhnel (Mount Kenya). G. T. Prior, Min. Mag. vol. xiii (1903) p. 247.
C = Leith Valley, Dunedin (N.Z.). Anal. P. Marshall.

The Dunedin rock differs but little in composition from the others quoted, although the higher percentage of potash is noticeable. Chemically the rock is more nearly related to the phonolites than to the basalts, and this is emphasized by a consideration of its mineralogical composition. No analysis was made of any of the specimens that show marked trachytoid or marked nephelinitoid structures.

The extent of the trachydolerite was fairly definitely outlined in my paper quoted above. The main area is found on the south side of Flagstaff, and on the south and west side of Pine Hill and Mount Cargill. Petrographically, the rock is closely related to the green phonolite of Mopanui and Blueskin, and in places where it has cooled very rapidly the same green colour is conspicuous. In no place has this rock been found interbedded with other lavas. In every one of its known occurrences it covers the surface, and no pebbles of it have been found in breccias or conglomerates. On the eastern side of Flagstaff the rock is certainly found near the base and half way up the slopes. It is, however, not likely that this position is due to a subsequent outpouring and covering by the rocks nearer to the summit of the hill, for no traces of the trachydolerite are to be found on the western side.

This occurrence is best explained by the supposition that the trachydolerite flowed downwards from Mount Cargill into a previously-eroded valley, wherefore some of it occupies a lower level than the previously-emitted and eroded lavas. This explanation is rendered more probable, when the fact is stated that the trachydolerite is in part at a lower level than the calcareous sandstone on the eastern flanks of Flagstaff, where it is exposed in Morrison's Creek.

14. Andesite.—There is a group of rocks, forming in places large and important lava-flows, which in their mineralogical composition occupy an intermediate position between the basalts and the trachytoid phonolites. The most typical of them occurs in the lower portion of the Leith Valley. It is a coarse-grained rock, with conspicuous phenocrysts of felspar, and occasionally of hornblende as well. In slices, the felspar is not much twinned, but has the extinction-angle of andesine. The hornblendes have a wide resorption-border; there are smaller crystals of brown augite, and some occasional pseudomorphs after olivine. The groundmass consists of felspar-microliths, augite, and magnetite. The rock is, therefore, considered to be a basic type of augite-andesite.

Inclusions of a plutonic nature are not uncommon in this rock. They are always a coarse diorite, consisting of andesine and brown hornblende in about equal quantity; there is also some pale brownish-green augite, large crystals of apatite, and a little magnetite. The apatites are rather peculiar, for they are in the form of short prisms, contain a great number of gaseous inclusions, and have a faint violet tinge. Apatite with the same character is found rather frequently in the andesite, and less frequently in other rock of the district.

Chemically, the andesite is rather poor in silica but relatively high in alkalies, showing in these respects a relationship to the trachytoid phonolites that are so abundant in this district.

	A. *Per cent.*	B. *Per cent.*
SiO_2	51·36	51·46
TiO_2	...	0·32
Al_2O_3	15·98	20·26
Fe_2O_3	7·64	4·64
FeO	5·10	3·56
MnO	...	0·32
CaO	6·50	9·55
MgO	1·84	3·16
Na_2O	4·26	4·29
K_2O	3·97	2·47
P_2O_5	0·42	0·57
H_2O	3·60	0·34
Totals	100·67	100·94

A=Andesite, Paper-Mills, Leith Valley, Dunedin (N.Z.). Anal. P. Marshall.
B=Hornblende-andesite with augite, Bogosloff I. (Alaska). Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 307, No. 16 *b*.

The amount of iron is high and alumina correspondingly low, as in most of these rocks. The substantial agreement in the analyses justifies the classification of the rock with the augite-andesites.

An amphibole from the andesite was also analysed, with the following result (A):—

	A.	B.
	Per cent.	*Per cent.*
SiO_2	42·36	39·29
TiO_2	...	4·86
Al_2O_3	17·66	16·57
Fe_2O_3	10·72	9·18
FeO	6·51	3·19
CaO	10·10	12·90
MgO	10·46	10·40
Totals	97·81	96·39

A = Hornblende from andesite, Dunedin (N.Z.). TiO_2 not determined.
B = Hornblende from andesite, Wolkenburg (Siebengebirge). Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 303, No. 4.

The alkalies were not estimated in either case. The comparison shows that the amphibole is of an ordinary type, and must be included among the pargasites; see Dana, 'System of Mineralogy' 6th ed. (1892) p. 396.

The principal occurrence is at the Paper-Mills and Golf-Links, and on the summit of Roslyn. The rock occurs below the trachytoid phonolites at the See House, and above the Papanui dolerite that is exposed there. The andesite forms a lava-flow about 100 feet thick. Mineralogically, it lies between a hornblende-basalt and a trachytoid phonolite.

15. Nepheline-basanites.—The most prominent phenocrysts in these are of nepheline, but olivine can generally be distinguished as well. Slices show that the nepheline is rounded, and fringed with a border of minute felspar-prisms. The olivine is rounded in the larger grains, but the smaller are sometimes idiomorphic. The rock is completely crystalline, the finer portions being composed of an intimate mixture of felspar, augite, and olivine. Many of the augites have a core of ægirine, with a mantle of brown augite. The felspar is labradorite. At first sight, one is inclined to regard the nephelines as xenocrysts; but their very regular occurrence throughout the rock, as well as the presence of some ægirine, compels the opinion that they form an essential constituent. An analysis showed that the rock does not differ very widely from other basanites:—

	A.	B.
	Per cent.	*Per cent.*
SiO_2	49·39	48·41
Al_2O_3	14·86	16·24
Fe_2O_3	7·35	4·89
FeO	5·42	6·41
CaO	7·08	9·38
MgO	5·62	7·25
Na_2O	4·71	3·23
K_2O	2·54	2·33
P_2O_5	0·20	—
H_2O	2·52	2·11
Totals	99·69	100·25

A = Basanite, Otago (N.Z.). Anal. P. Marshall.
B = Basanite, Hesse. U.S. Geol. Surv. Prof. Paper No. 14, 1903, pp. 322–23.

The large number of rounded grains in the basanites at once distinguishes hand-specimens of the rock from those of other basic rocks of a similar black colour. On the other hand, the phonolitic rocks that contain large crystals of nepheline have a dark-green tint.

There is no large area covered with outcrops of the rock. It is confined to the eastern slopes of Flagstaff, the slopes of Mihiwaka, and to North Otago Head. In the first-named locality it underlies a Papanui type of dolerite, which is covered by a basalt, and finally by a trachytoid phonolite. Much the same arrangement is found at the North Head and on the northern slopes of Mihiwaka. At Waikouaiti, boulders of the rock occur in a conglomerate that is covered by a basaltic lava-flow.

16. Dolerites.—The word dolerite is here used as a term covering all the types of coarse basic rocks, irrespective of age, if they are of effusive character.

The Mount-Charles type contains large conspicuous phenocrysts of olivine, augite, and felspar. In slices, the big olivines are found to be rounded and in parts serpentinized. The augites have a pale-green core (diopside), but a brown margin. The core is usually of irregular shape, but the mantle corrects the irregularities, and gives a completely-idiomorphic form to the crystals. The felspars are but little twinned; the extinction-angle, however, is high, and shows that the mineral is labradorite. The groundmass is crystalline, and consists of felspar, augite, and magnetite.

The Papanui type is an even-grained rock, except that the olivines are rather larger than the other constituents. In slices, the rock is quite coarsely crystalline, and often shows an ophitic structure. The augite was the last constituent to crystallize, and is markedly allotriomorphic. The felspar is in highly-twinned elongated crystals: the species is labradorite or bytownite. There is much magnetite present. The rock is always coarse-grained and distinct, but in one example (Harbour Cone) the place of some of the augite is taken by a brownish glass, with branched growths of magnetite. This example should properly be called a basalt; but it is so closely allied to this dolerite, and so different from the ordinary basalts of the region, that I have always considered it as a member of this group.

Two specimens of the Papanui type of dolerite, collected from widely-different localities, were analysed; and one specimen of the Mount-Charles type was taken for comparison:—

	A.	B.	C.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	45·39	44·84	48·40
Al_2O_3	9·61	11·92	13·05
Fe_2O_3	9·27	9·12	9·02
FeO	8·48	8·54	7·33
CaO	9·25	9·23	8·30
MgO	10·69	10·34	7·26
Na_2O	3·14	1·43	3·50
K_2O	0·55	0·68	0·57
H_2O	2·81	3·04	2·84
Totals	99·19	99·14	100·27

A & B=Papanui Dolerite; C=Mount-Charles Dolerite.

They are evidently both rather basic types of rock; but there does not appear to be any indication in the analyses of the cause that has made them, during their solidification, assume states of crystallization so very different.

In one outcrop on the shore of Papanui Inlet, large fragments of quartz are contained in abundance in the Papanui Dolerite. They are of all sizes, up to 6 centimetres in diameter. Their structure shows that they are derived from schist that has been broken off during the ascent of magma through it. In slices, the margin of the quartz is seen to have a dense felt of augite-crystals, with their longer axes at right angles to the margin.

(A) The Mount-Charles type forms extremely-large lava-flows at the centre and east of Otago Peninsula. One of these is well-exposed at the Natural Bridge, Sandy Mount, where it is 300 feet thick and has a well-marked, coarse, columnar structure. Almost the whole of the Mount-Charles Peninsula is composed of it. Except for two small patches at Whare Flat and Blanket Bay, it has not been found to the north or west of Otago Harbour. At the Natural Bridge, it rests upon a thick breccia of basic rock. Near Portobello, it is much invaded by trachyte. A dyke of it penetrates a basic breccia at the southern head of Hooper's Inlet. At the north side of Hooper's Inlet there is apparently an intrusion of trachyte into it, and a dolerite of the Papanui type either intrudes into it or underlies it.

It appears, therefore, that this rock is one of the oldest of the whole series; for it is, in the Portobello area, older than the trachyte, itself the lowest of the rocks in this area, which is the centre of the whole volcanic district.

(B) The Papanui type is the most widespread of all the rocks of the area. At Sea View, it lies directly upon the calcareous sandstone. By Otago Harbour, opposite Logan's Point, it occurs below the trachytoid phonolite. At the See House, it is below the andesite and the trachytoid phonolite. It appears to have been the product of one of the older eruptions, and apparently ceased before the emission of any trachytoid phonolite.

This rock—or at any rate a type indistinguishable from it by microscopic methods—occurs over a wide area in Otago; for it is found at Waifiata in Central Otago and at Puketapu near Palmerston North, and a very similar rock occurs at Banks Peninsula. The specimens obtained at Papanui Inlet are coarser than any that are found elsewhere.

17. Basalt.—There is a great variety of basalts in the Dunedin area. They vary from comparatively-acid types, to others that are almost limburgites.

At High Cliff, a basalt occurs, with very little olivine and a fine-grained groundmass of pale augite and felspar-microliths, giving to the rock a pilotaxitic structure. At Sea View, the olivine-grains are very large and conspicuous, the augites of moderate size, and

the groundmass very fine. At Papanui Inlet, and at a few other localities, hornblende-basalts occur, showing the ordinary dark-brown hornblendes with a resorption-border.

Occasionally, types are found in which a small quantity of brown glass remains; and at Sandy Mount there are fragments in a scoria-bed that consist almost solely of a brown glass, in which are dispersed some felspar-microliths and magnetite-grains.

In the upper part of the Leith Valley occurs a very basic type. It contains large inclusions of olivine, which in section show some picotite and diopside. Smaller olivines are numerous. There is no felspar; but granular augite and magnetite constitute the remainder of the rock.

In nearly all instances, the olivine of the basalts is more or less decomposed. Usually the change has resulted in a mere staining with limonite; but in many cases there is a more or less complete change to serpentine.

There is no striking chemical peculiarity in the basalts, so far as they have been examined, except that the percentage of alumina is rather high. A quantitative analysis of an ordinary example has been made, with the following result:—

SiO_2	45·28
Al_2O_3	19·01
Fe_2O_3	8·52
FeO	5·01
MgO	5·14
CaO	7·55
Na_2O	2·66
K_2O	2·51
H_2O	2·99
Total	98·67

Very many lava-flows and some dykes of basalt occur in the district. No attempt has been made to separate the types of basalts into groups, although it appears as if the nature of the dominant pyroxene might be taken as a basis.

There is no doubt that some of the basalts are intrusive, and represent pipes of former small cones. This is well seen at St. Clair, Black Head, and at Mount Cargill, where the northern peak is formed of a columnar basalt, while in the first two localities the basalt-neck penetrates through the calcareous sandstone.

From the section at North Otago Head, it is evident that basalt-flows followed the effusion of trachyte. They were succeeded by a flow of trachytoid phonolite. Basalt again succeeded, with a brief change to basanite, and finally a second trachytoid phonolite.

Basalts appear to have been almost the last of the lavas emitted, for basalt-flows cover the conglomerates at Kaikorai, Waikouaiti, and at Union-Street Bridge; and pebbles of trachytoid phonolite, and of nearly all the other types of rock, occur abundantly in the conglomerates. The andesitic type of trachytoid phonolite is poorly

represented, and there are no pebbles of trachydolerite, so far as known.

18. Melilite-basanite.—A dark basaltic rock, exhibiting distinct grains of olivine in hand-specimens. Slices show some plagioclase, the extinction-angle of which is high enough for anorthite; augite, generally granular and very abundant; olivine in rather long crystals. Melilite was the last mineral to crystallize, and is present in irregular plates containing inclusions of augite, anorthite, and magnetite. No perofskite has been detected. The presence of felspar in these rocks appears to be exceptional: in consequence of its presence, the rock should be classed as a basanite.

It is only in the extreme northern part of the district that any melilite has been found up to the present. The rock forms a lava-flow of some 50 feet thick, resting upon the calcareous sandstone below and covered by trachytoid leucite-phonolite above. Field-indications point to the probability that the rock covers a large area, but this has not yet been proved by microscopical investigation. Occurring as it does, right on the edge of this volcanic district, it is difficult to say what position it would occupy in the complete series of rocks: but it is probable that it is the equivalent of one of the younger basalts, immediately below the trachytoid phonolite in the main series.

19. Port-Chalmers Breccia.—In many places the component fragments are large, reaching 60 centimetres in diameter; but usually they are quite small, and in some large masses of rock it is unusual to see any fragments of greater size than 10 cm. The fragments are very variable in nature. Pieces of mica-schist, diorite, and dolerite are not infrequent. Nepheline-syenites are fairly frequent; and tinguaites (porphyritic and dense), phonolites, and basalts are abundant. In sections, much of the microscopic matter is seen to be phonolite and trachyte. Occasional crystal-fragments of felspar and augite occur. The rock is firmly coherent, and the grains are held together more by the compact nature of the fine material in which they are embedded, than by any definite cement.

The Port-Chalmers Breccia is a fine to coarse clastic rock, closely cemented into a hard coherent mass by consolidation and cementation. It covers a large area near Port Chalmers, and is also found to the west and south of Hooper's Inlet. It lies above the trachyte, with which it is in contact, but is covered by trachytoid phonolite.

The breccia evidently represents the detritus thrown out from a crater in which violent spasmodic steam-explosions occurred. All the rocks previously deposited in the neighbourhood were shattered, and in the constant attrition attending their emission and falling back were partly reduced to powder: this has formed the cementing-material which has converted the fragmentary matter into a hard coherent rock. It is a noteworthy fact that the majority of the tinguaite-dykes radiate from a spot near the present greatest thickness of breccia—Observation Point; and it is probable that the

tremendous steam-explosions to which this breccia owes its formation also rent the neighbouring rocks asunder, and the alkaline magma that filled the rents solidified into tinguaite-dykes.

The formation of the Port-Chalmers Breccia appears to have succeeded the effusion of much of the basalt and the trachyte, but it must have preceded the eruption of most of the trachytoid phonolite and the trachydolerite.

Many other breccias of small thickness and limited extent are found between various lava-streams, but none of them have the importance of the Port-Chalmers rock.

III. Chemical Classification.

An attempt has been made to classify the Dunedin rocks that have been analysed, in accordance with the scheme of quantitative classification formulated by Prof. Pirsson, Dr. Washington, Prof. Iddings, and Mr. Weed. The calculations necessary to find the proper place in the classification are slightly involved, and there is no certainty that a correct result has been achieved in every case.

The alkaline rocks of the district form so well-defined a series, that they constitute a good test for any system of classification, although it must be allowed that fuller (and perhaps more exact) analyses, with separation of titanic oxide and other compounds, are desirable in order to ensure satisfactory results.

A tabulated statement of the classification of the rocks is here appended. It is framed in accordance with the large and valuable collection of analyses, calculated according to the system proposed by Dr. H. S. Washington, which was published in 1903 by the United States Geological Survey as Professional Paper No. 14. It will be seen, in every case, that the rocks fall into classes containing many similar species described from other parts of the world.

Class I. PERSALANE.
- Order 5. Perfelic.
  - Rang 1. Peralkalic.
    - Subrang 4. Dosodic.
      - Trachyte, Portobello.
      - Tinguaite, Acheron Point.
- Order 6.
  - Rang 1.
    - Subrang 3. Sodipotassic.
      - Trachytoid Phonolite, Logan's Point.

Class II. DOSALANE.
- Order 5.
  - Rang 1.
    - Subrang 4.
      - Green Phonolite.
  - Rang 2.
    - Subrang 4.
      - Camptonite.

Order 6.
Rang 1.
Subrang 3.
Nephelinitoid Phonolite, Mopanui.
Leucitophyre.
Trachydolerite.
Subrang 4.
Camptonitic Tinguaite.
Trachytoid Phonolite.
Rang 2.
Subrang 3.
Andesite.
Subrang 4.
Trachytoid Phonolite.

Class III. SALFEMANE.
Order 5.
Rang 3.
Subrang 5.
Dolerite, Mount Charles.
Dolerite, Papanui.
Order 6.
Rang 2.
Subrang 4.
Basanite.

In Class I it is seen that the trachyte from Portobello and the tinguaite from Acheron Point fall into the same subrang. It is evident that a classification in which this happens is hardly satisfactory from a petrographical standpoint, for the mineralogical composition, structure, and geological occurrence of the rocks are all different. On the other hand, both rocks belong to the alkaline series, and the slight chemical difference, although sufficient to disturb the mineralogical formation, is insufficient to allow of separation of the rocks according to this system, which is based on chemical characters alone.

This class includes a lestiwarite, an andesite, a porphyrite, and a sölvsbergite; therefore, the two rocks here included do not correspond to the extremes that are possible. In the same class, but in a different order and subrang, is the Logan's-Point phonolite. There is no doubt as close a relationship geologically and petrographically as in this classification.

The majority of the alkaline rocks find their places in the second class, and in closely-related divisions of that class. The andesite and green phonolite are in slightly-different divisions. The classification here seems to agree satisfactorily with the relationships as expressed by mineralogical composition. However, the rocks in Order 6, Rang 1, Subrang 3 are very different in many particulars, and hardly any petrographers or mineralogists could be content with such a result, for mineral constituents, structure, and occurrence are all different. It is true that, at present, our knowledge is too scanty to allow of any formulation of a natural or genetic system

of classification; but this is the natural final goal, and present attempts and descriptions should be largely based on those characters that evidently are important from a genetic standpoint, although their full significance is unknown. The suggested classification seems to lose sight of these characters, and therefore neglect and indifference to them would follow its general adoption, to the great loss of petrography.

A classification according to the petrographical or mineralogical characters of the rock in each subrang would probably lead to endless overlapping and confusion. In a word, it may be said that, so far as the present group of rocks is concerned, the suggested chemical classification, while grouping them according to their chemical relationships, is unsatisfactory from a geological standpoint.

The amount of care and thought that has been expended in framing the system must have been almost colossal, and whether the result is accepted as satisfactory or not, it must have a helpful and salutary influence, of a marked nature, on the progress of petrographical science.

An attempt was made to discover any further possible relationships between the rock-groups, by representing their chemical composition by graphic methods. The diagrams, however, did little more than figure forth the facts already mentioned:—

(1) That the alkaline rocks show a graduated series, from the trachytes through the tinguaites, to the least acid type of the trachytoid phonolites.

(2) That the basic rocks are also closely related one to the other.

(3) That the trachydolerites and basanites form connecting-links, the former being closer to the alkaline series, the latter to the basic.

It was considered that these facts were sufficiently evident, without being further emphasized by the reproduction of the diagrams.

IV. Origin of the Different Kinds of Rocks.

It is obvious that the occurrence of so many different kinds of rocks in one district would, if interpreted correctly, throw considerable light on the much discussed cause of the differences between igneous rocks.

So far as the succession of lavas is concerned, there are two sections that display the actual relative position of lavas that seem to be of prime importance.

The first (fig. 1, p. 417) is exposed along the side of the Water of Leith from the corner of Duke Street and Royal Terrace to Skey's House. Here the lowest rock is a basalt: a flow of Papanui Dolerite 50 feet thick rests upon the basalt, and above the dolerite comes an andesite. This is succeeded by two flows of trachytoid phonolite, above which comes a basalt, and finally the series in this district is completed by a trachydolerite.

Unfortunately, information is not at present complete as to whether the basalts occurring in the different parts of this series are similar in composition; but, leaving them out of consideration, the silica-ratio increases from the dolerite to the trachytoid phonolite, then decreases in the trachydolerite, in the ratio 44 : 51 : 55 : 52.

Fig. 1.—*Section along the Leith Valley, from See House to the Reservoir.*

[Scales, vertical and horizontal: 4 inches = 1 mile.]

1 = Basalt. 2 = Papanui Dolerite. 3 = Andesite. 4 = Trachytoid phonolite (andesitic type: two flows). 5 = Trachydolerite.

The alkalies, on the other hand, constantly rise if the upper basalt be not considered. The minerals of these rocks are as follows:—

Dolerite.	Andesite.	Trachytoid Phonolite.	Trachydolerite.
Anorthite.	Labradorite.	Oligoclase.	Sanidine.
Augite.	Augite.	Ægirine-augite.	Anorthoclase.
Olivine.	Hornblende.	Hornblende.	Ægirine.
Magnetite.	Olivine (little).	Magnetite.	Augite.
	Magnetite.	Nepheline (microchemical tests).	Olivine.
			Hornblende (resorbed).
			Nepheline.
			Sodalite.
			Magnetite.

Both chemically and mineralogically, there seems to be, in this case, little support for the theory of magmatic differentiation, for the order is basic, intermediate, alkaline-basic, alkaline-basic.

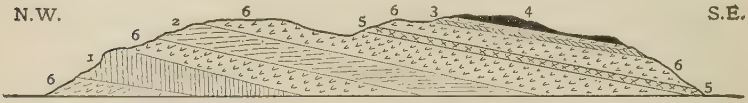
The minerals are different in the lavas. The heavy mineral hornblende is not present in the heaviest rock. The heaviest mineral olivine is present in the last rock erupted, which is a comparatively-light one.

The resorption-zones of the hornblende in the andesite show that it was unstable in this rock, but was much more stable in the trachytoid phonolite, and was completely resorbed in the trachydolerite.

The other important section (fig. 2, p. 418) is exposed at North Otago Head. Here the lowest rock seen is basalt. Upon this rests trachyte. It is succeeded by basalts, and they give place to a trachytoid phonolite of a highly-alkaline type. Basalts succeed this for 200 feet in ten distinct flows. Then comes a phonolite rich

in hornblende, of the St. Leonard's type, with two basalts above it. Finally the crest is crowned by another trachytoid phonolite, less alkaline than the earlier one.

Fig. 2.—*Section at North Otago Head.*



[Scales, vertical and horizontal: 4 inches =1 mile.]

1=Trachyte.
2=Trachytoid phonolite (Logan's-Point type).
3=Trachytoid phonolite (St. Leonard's type).
4=Trachytoid phonolite (andesitic type).
5=Basanite.
6=Basalt (twenty lava-flows).

No analyses have yet been made of this series of rocks, but sections fail to show any resemblance whatever between the different rocks or their component minerals; except that the basalt immediately above the lower trachytoid phonolite contains ægirine-augite, and is certainly more alkaline than the higher basalts. A basanite with large nepheline-crystals is exposed at the northern end of the cliff, and appears to extend throughout it as a lava among the basalts, but it has not yet been definitely traced in that precipitous portion where the succession is clear.

The general section (fig. 3, p. 420) across the whole district, from west to east, is less instructive. The coarse trachydolerite that forms the southern portion of Mount Flagstaff is believed to be intrusive, and to represent the neck of a volcano, from which much trachydoleritic lava was erupted.

On the east side of Mount Flagstaff a succession of lavas of very various character is found, and an attempt has been made to represent their probable arrangement. The trachydolerite which occurs over some portion of the western side of the Leith is supposed to have flowed from Mount Cargill into a valley that was already eroded. The Pine-Hill mass flowed from Mount Cargill apparently over a great thickness of trachytoid phonolite, of which all the central and southern part of Signal Hill is composed. The capping of basalt on the top of Signal Hill flowed from a vent farther north. Trachyte is found near the shore of Otago Harbour, and forms the main mass of that portion of the peninsula which lies opposite to it; but the occurrence of basalt on this shore-line indicates that it lies beneath the mass of trachyte. A dolerite occurs at the top of Harbour Cone, and seems to have been intruded through the trachyte at the eastern base of the Cone, where the foyaite occurs. Mount Charles is almost entirely composed of the type of dolerite named after it.

There are three sources of information in regard to the succession of the lavas :—

1. Actual superposition.
2. Occurrence of pebbles and boulders in breccias and conglomerates that are covered by other lavas.
3. Dykes penetrating other rocks.

The first of these has been discussed in the pages just preceding; the second was referred to when the conglomerates and breccias were described; the third is not very suggestive, but the more important points may here be mentioned :—

Tinguaites penetrate alike the Mount-Charles Dolerite, the trachyte, and the trachytoid phonolite.
Basalt traverses Mount-Charles Dolerite and trachyte.
Camptonite penetrates trachyte and Mount-Charles Dolerite.

The following is the most probable order of rock-formation that can be suggested when the preceding facts are borne in mind :—

1. Basalt and Mount-Charles Dolerite.
2. Trachyte.
3. Basalt.
4. Trachytoid phonolite, highly alkaline.
5. Basalt.
6. Basanite.
7. Papanui Dolerite and basalts.
8. Andesite and St. Leonard's type of phonolite.
9. Port-Chalmers Breccia.
10. Trachytoid phonolite (andesite).
11. Basalt.
12. Trachydolerite and nephelinitoid phonolite.
13. Basalt.

The other lavas have not been discovered in positions which allow of their relative age being gauged.

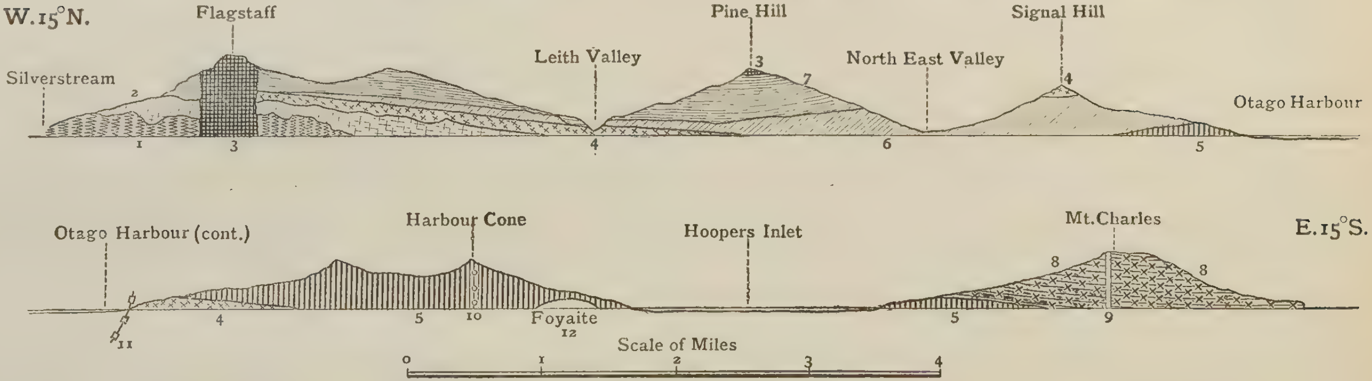
This order of emission does not seem to follow any of those that are suggested by theories of magmatic differentiation. The difficulties encountered are especially great, when the small sections at Sec House and North Otago Head are considered. Such an occurrence as that at the top of Mount Cargill is also very complex. The mountain has five peaks, large and small. The main one is composed of trachydolerite; another close to it of nephelinitoid phonolite; two others of trachytoid phonolites of different types; and the fifth of basalt. Vegetation so hides all the intervening ground, that no conclusions whatever can be reached as to the relative age of the rocks.

It is believed, however, that in this district the microscopic structure of the rocks affords very important aid in arriving at conclusions as to the origin of the numerous rock-types observed.

In the dolerites, most of the basalts, the trachyte, and some trachytoid phonolites, all the minerals seen in the rocks appear to be native to them. None of the constituents show signs of corrosion or resorption or marginal fringes.

Fig. 3.

Section 15¾ miles in length, from W 15°N. to E. 15° S., across the Dunedin volcanic district.



1 = Crystalline schist.
2 = Tertiary calcareous sandstone.
3 = Hypabyssal trachydolerite.
4 = Basalt.
5 = Trachyte.
6 = Trachytoid phonolite.
7 = Trachydolerite.
8 = Mount-Charles Dolerite.
9 = Phonolite-dyke.
10 = Dolerite-dyke (Papanui type).
11 = Tinguaite-dyke.
12 = Foyaite.

In the basanite, the nepheline and sodalite are much corroded, and the pyroxene has a core of ægirine. It seems impossible that in such rocks these alkaline minerals should have formed first, and have suffered corrosion afterwards. For, in a rock with so high a percentage of silica (49), and a comparatively-low percentage of lime (7), a soda-lime felspar would have been formed in sufficient quantity to use up all the available soda (4·7). Even in those rocks where the silica-percentage is so low that there is more soda than can be utilized in the felspar, it is, so far as specimens available for examination in Dunedin are concerned, retained in the magma until the last stage of crystallization is reached, when idiomorphic nepheline separates out, and the augite becomes fringed with a mantle of ægirine. This, which appears to be the normal order in such rocks, is admirably shown in rocks from Auckland (N.Z.), also in those from the Lobauer Berg.

In the trachydolerites, the augite and olivine appear to be as little true secretions from the magma of the rock in which they are contained as the nepheline and ægirine in the basanites. Not only has resorption proceeded far while fringes of ægirine have formed round the minerals, but the augite must have been (with olivine) the earliest constituent to form. In addition, the only plutonic fragment found in the rock (it is 10 centimetres in diameter) contains no olivine or augite, though all the other trachydolerite-constituents are present.

There can be no doubt that the dolerite at Papanui has obtained large quantities of quartz now partly resorbed from the schist. In connexion with this, it is only necessary to refer to marscoite, a rock formed from a gabbro-magma that has taken up granitic material prior to its intrusion and to the 'composite sills.'[1]

In a word, all these minerals must be regarded as xenocrysts in the rocks in which they are found. The question arises as to whence these xenocrysts were derived. It is unlikely that they were obtained from the melting of rocks previously solidified, for the amount would have to be enormous, and the stage of melting in the huge mass of trachydolerite, for instance, is the same all through. Again, if any melting of adjacent rocks took place, it is natural to expect that the quartz contained so abundantly in the mica-schist, the fundamental rock of the district, would be well represented.

The only rational explanation appears to be that these rocks have resulted from mixture of magmas before ejection.

The nature of the magmas before this mixing cannot be more than guessed at until further research is made, but the trachyte- or phonolite- and dolerite-magmas appear more likely than the others. It is possible that these two magmas owe their original separation to magmatic differentiation, but whether that is so or not, the ultimate cause in producing the numerous varieties of rocks would appear to be magmatic mixing.

[1] A. Harker, 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. U.K. (1904) chapt. xii.

The Papanui Dolerite has a wide occurrence in Otago, and is extremely uniform in structure and composition. The trachyte and alkaline trachytoid phonolites are also very closely related, very uniform, and are of widespread occurrence in the Dunedin area.

The obvious criticism that must be first offered concerning this explanation, is the complete mixing that the magmas have undergone. Both the basanites and the trachydolerites appear to be uniform and homogeneous throughout. The passage of steam-bubbles through the magma, and the flow-movements consequent on eruption, seem to me inadequate to account for so complete a mixing. Yet, admitting this apparent inadequacy, the explanation is perhaps more satisfactory than any that might be based upon magmatic differentiation.

V. Summary.

The Dunedin district is a distinct petrographical unit. The igneous rocks are of post-Oligocene age.

The igneous rocks are very variable in nature, embracing plutonic, hypabyssal, and volcanic members. They range in their petrographical character from very basic dolerites to highly-acid and alkaline trachytes.

Complete descriptions are given of many typical members of the several groups.

The geological occurrence of the rocks is described.

Chemical analyses show that the petrographical differences are often coincident with chemical differences, and also that they are generally similar to rocks of the same classes in other parts of the world, more particularly to those of East Africa.

A classification is attempted, according to the methods proposed by distinguished American petrologists.

Sections are described that indicate the order of succession of the lavas. This order does not appear to be explicable on any theory of magmatic differentiation, but it is suggested that it may be due to the mixing of magmas before and during eruption.

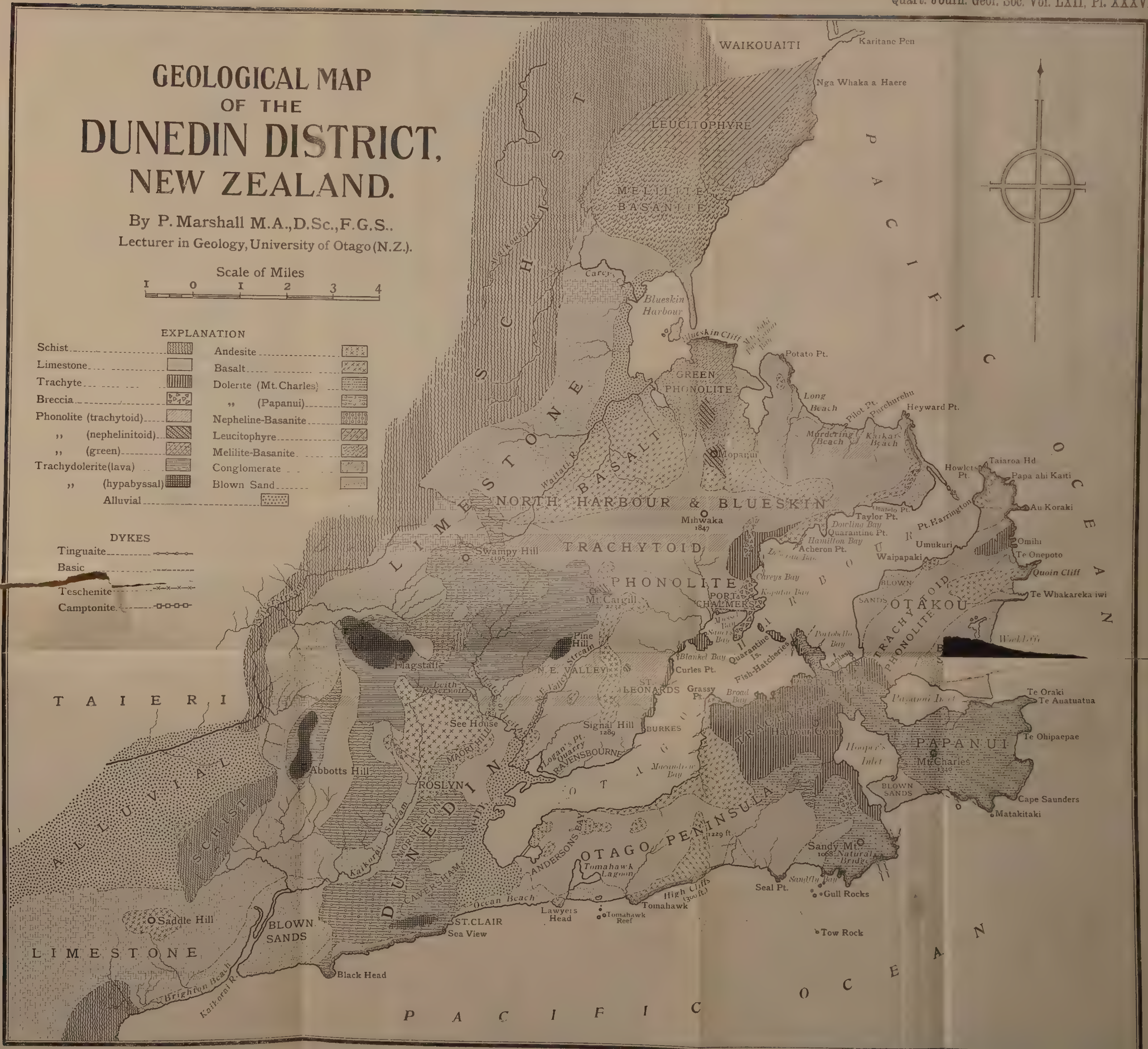
Postscript.

[Prof. Rosenbusch, with characteristic enthusiasm, has kindly examined slides of many of the rocks described in the foregoing pages, and his remarks on them have just reached me. In nearly all respects he agrees with the classification that I have adopted, but there are some important points as to which his wide experience and knowledge have prompted him to give me important information:—

The diorite of Bell Hill he classes as an exceptional form of essexite.

The andesite of the Paper-Mills and the trachytoid phonolite of St. Leonard's are, he says, rather more closely allied to the trachydolerites than to the classes in which I have placed them. The former he regards as closely similar to the 'andesite' of the Siebengebirge.

The camptonite also he refers to the trachydolerite-group.



GEOLOGICAL MAP
OF THE
DUNEDIN DISTRICT,
NEW ZEALAND.
By P. Marshall M.A., D.Sc., F.G.S.,
Lecturer in Geology, University of Otago (N.Z.).
Scale of Miles
1 0 1 2 3 4
EXPLANATION
Schist
Limestone
Trachyte
Breccia
Phonolite (trachytoid)
,, (nephelinitoid)
,, (green)
Trachydolerite (lava)
,, (hypabyssal)
Alluvial
Andesite
Basalt
Dolerite (Mt. Charles)
,, (Papanui)
Nepheline-Basanite
Leucitophyre
Melilite-Basanite
Conglomerate
Blown Sand
DYKES
Tinguaite
Basic
Teschenite
Camptonite
WAIKOUAITI
Karitane Pen
Nga Whaka a Haere
LEUCITOPHYRE
MELILITE BASANITE
SCHIST
Blueskin Harbour
Potato Pt.
GREEN PHONOLITE
Long Beach
Pilot Pt.
Heyward Pt.
Murdering Beach
Kaikai Beach
Mopanui
Taiaroa Hd
Howlets Pt.
Papa ahi Kaiti
Au Koraki
LIMESTONE
BASALT
NORTH HARBOUR & BLUESKIN
Mihiwaka 1847
Taylor Pt.
Dowling Bay
Quarantine Pt.
Hamilton Bay
Acheron Pt.
Pt. Harrington
Umukuri
Omihi
Te Onepoto
Waipapaki
Quoin Cliff
Te Whakareka iwi
Swampy Hill 1951
TRACHYTOID
PHONOLITE
Mt. Cargill 2217
Careys Bay
PORT CHALMERS
HARBOUR
BLOWN SANDS
OTAKOU
TRACHYTOID PHONOLITE
Pine Hill
Flagstaff
N. E. VALLEY
Quarantine Is.
Fish-Hatcheries
Portobello Bay
Blanket Bay
Curles Pt.
Leith Reservoir
ST. LEONARDS
Grassy Pt.
Broad Bay
TAIERI
See House
Signal Hill 1289
BURKES
Harbour Cone
Hooper's Inlet
Papanui Inlet
Te Oraki
Te Anatuatua
Te Ohipaepae
PAPANUI
Mt. Charles 1339
Logan's Pt. Quarry
RAVENSBOURNE
MAORI HILL
Abbotts Hill
ROSLYN
DUNEDIN
OTAGO
Macandrew Bay
BLOWN SANDS
Cape Saunders
Matakitaki
ALLUVIAL
SCHIST
MORNINGTON
Kaikorai Stream
ANDERSONS BAY
OTAGO PENINSULA
1229 ft
Sandy Mt. 1068
Natural Bridge
Tomahawk Lagoon
CAVERSHAM
Ocean Beach
High Cliffs (300 ft.)
Seal Pt.
Sandfly Bay
Gull Rocks
Saddle Hill
BLOWN SANDS
ST. CLAIR
Sea View
Lawyers Head
Tomahawk Reef
Tomahawk
Tow Rock
LIMESTONE
Black Head
Brighton Beach
Kaikorai R.
PACIFIC OCEAN

Fig. 1.

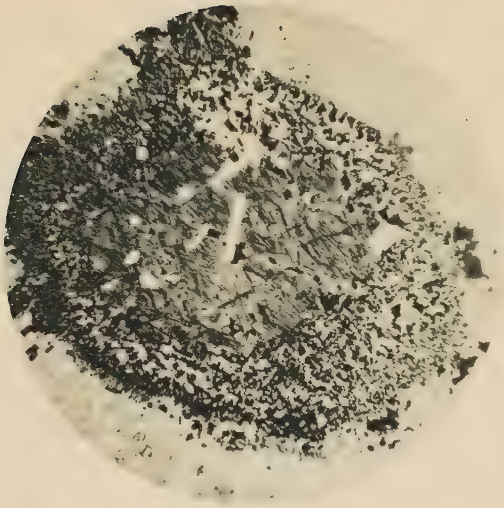


Fig. 2.

ROCKS FROM THE DUNEDIN DISTRICT (N.Z.).

P.M. Photomicro. *Bemrose, Collo.*

FIG. 1.

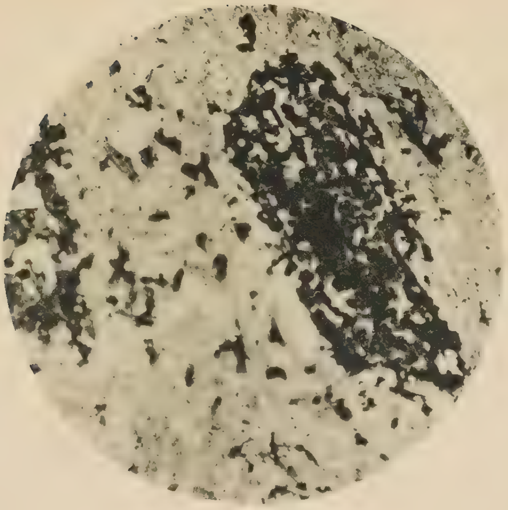


FIG. 2.

ROCKS FROM THE DUNEDIN DISTRICT (N.Z.).

P.M. Photomicro. *Bemrose, Collo*

FIG. 1.

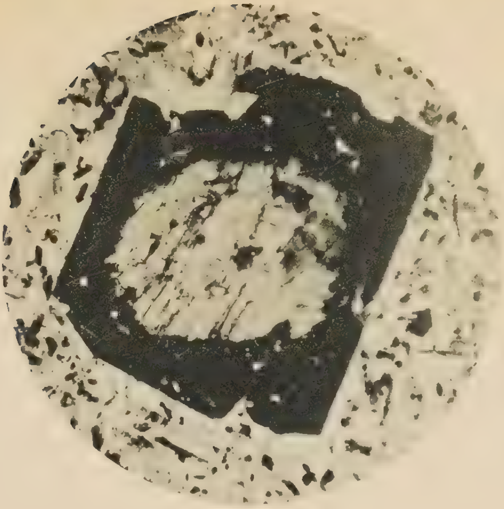
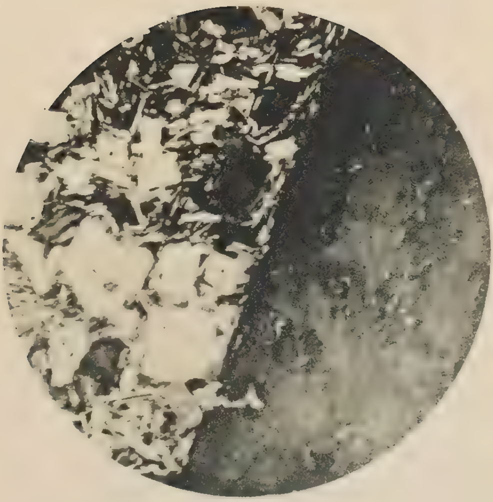


FIG. 2.



ROCKS FROM THE DUNEDIN DISTRICT (N.Z.)

P. M. Photomicro. Bemrose, Collo.

The spherulitic structure in the tinguaite of Hooper's Inlet he ascribes to zeolitization, especially the formation of natrolite.

The spherulitic structure of the Blueskin phonolite is cousidered by him as very remarkable and exceptional.

In most other essential respects he approves of the classification that I have adopted, so far as he has been able to judge from the rock-slices sent him—that is, in all those instances concerning which I was in doubt.—*P. M., November 15th, 1905.*]

EXPLANATION OF PLATES XXXVI–XXXIX.

[The numbers B 165, etc., in Pls. XXXVII–XXXIX are those of the microscope-slides preserved in the author's collection.]

Plate XXXVI.

Geological map of the neighbourhood of Dunedin, on the scale of 2 miles to the inch.

Plate XXXVII.

Fig. 1. B 165. Foyaite; Harbour Cone. Crystal of amphibole largely resorbed, with a rim of pyrites and ægirine and inclusions of apatite. It is surrounded by decomposed felspar. × 45 diameters.

2. B 22. Tinguaite; Limekilns, Otago Peninsula. Large crystal of nepheline, embedded in a groundmass of nepheline-, ægirine-, and anorthoclase-microliths. × 45 diameters.

Plate XXXVIII.

Fig. 1. C 4. Tinguaite; Hooper's Inlet. Resorbed amphibole, replaced by ægirine and analcite. Groundmass of felspar and nepheline. × 45 diameters.

2. C 75. 'Analcite-rock.' Camptonite showing camptonitic structure. Crystals of amphibole in a groundmass of analcite and felspar. × 45 diameters.

Plate XXXIX.

Fig. 1. C 6. 'Analcite-rock' (camptonite). Rounded grain of pink pyroxene surrounded by amphibole. Groundmass of amphibole, analcite, and felspar. × 45 diameters.

2. C 183. Kaiwekite; Kaikorai Valley. Large crystal of anorthoclase embedded in a groundmass of isometric felspars and felspar-laths. × 45 diameters.

Discussion.

The Chairman (Mr. R. S. Herries) congratulated the Society on the presence of such an old and valued Fellow as Capt. Hutton, whose last appearance at one of their meetings had been at Somerset House, in the days of Lyell and Murchison. On behalf of the Society he welcomed him back to England, and thought that the Fellows were much indebted to him for the able way in which he had presented this very interesting paper. Although he (the Chairman) had visited New Zealand, he had not been so far south as Otago, and in the districts that he had seen (those of Auckland, the Waikato, the Hot Lakes, the Otira Gorge, etc.) he had paid more attention to the physiographical conditions than to the rocks. He had, however, noted

the great difficulty of the country to be worked, and the vast opportunities awaiting the geologists settled there. He thought that this the parent Society was always very fortunate in receiving the best of their work from its children living in all parts of the world, and especially in having presented to it such an able paper from a colony so interesting as New Zealand.

Dr. TEALL regretted that he had not heard the first part of the paper, and could not therefore do justice to it; but he was glad of the opportunity of expressing the pleasure that he felt, in listening to even a small portion of what was evidently an important communication, and at meeting Capt. Hutton, with whose name and work he had been so long familiar.

Various theories had been proposed to explain the succession of igneous rocks, but none was applicable to all instances. This being the case, it was most important that the sequence in a large number of instances should be carefully recorded, and on those grounds he welcomed this paper. Of late, the view that the mixing of magmas and the modification of magmas by the absorption of adjacent rocks were important factors in determining varieties of igneous rocks had been gaining ground. He had not himself met with evidence of this on a large scale, but he was perfectly prepared to believe that it existed.

Prof. WATTS congratulated the Author on the richness of the petrology of the Dunedin district. He referred especially to the fact that the Author had tested the new classification in his rock-sequence, and had found it wanting.

Prof. HULL enquired as to the evidence of the former elevation of the area described to 1500 feet above its present level.

Mr. A. P. YOUNG, commenting on the persistence of the basalts which appear in the earliest, and last till the latest, stage of volcanic activity, said that he wished to ask whether some apparent repetitions in the series might not be referred to faults. As an alternative to the Author's hypothesis of the complete disappearance of amphibole through resorption, the speaker suggested that the presence or absence respectively of the mineral in closely-allied rocks might, in some cases, be explained by the tendency of amphibole to crystallize out at great depths from magmas which, at higher levels, yielded biotite or pyroxene in place of amphibole.

Mr. H. H. THOMAS asked a question concerning the Author's explanation of the occurrence of analcime in some of the rocks.

Capt. HUTTON, replying on behalf of the Author, said that the latter gave no theory as to the occurrence of analcime in the rocks. With reference to the question asked by Prof. Hull, there was a general agreement, both biological and geological, in favour of an elevation of the New Zealand area in later Pliocene times. The actual elevation in the south of New Zealand was estimated from the depths of the fiords below sea-level.

16. TRILOBITES *from* BOLIVIA, *collected by* Dr. J. W. EVANS *in* 1901–1902. By PHILIP LAKE, M.A., F.G.S. (Read April 25th, 1906.)

[PLATE XL.]

THE trilobites brought home by Dr. Evans are comparatively few in number, but nevertheless they form a valuable addition to our limited knowledge of the Lower Palæozoic faunas of South America. Several horizons are represented, and it is worthy of remark that, while the earlier forms show affinities with the contemporaneous European fauna, the Devonian species are much more closely allied to those of South Africa and North America. This observation is borne out by an examination of the trilobites described by Prof. E. Kayser from Argentina,[1] by Dr. A. Ulrich from Bolivia,[2] and by Dr. J. M. Clarke from Brazil.[3]

The following forms have been identified:—

Peltura sp.
Symphysurus Apolonista, sp. nov.
Trinucleus boliviensis, sp. nov.
Ogygia sp.
Phacops cf. *arbuteus*, Lake.
Dalmanites Paitúna, Hartt & Rathbun (?).
Dalmanites Maecurúa, J. M. Clarke (?).
Dalmanites sp.

The specimens were obtained from the following localities[4]:—

(1) Cochaiya, about 3 miles north-east of Pata, on the track from Apolo to Pelechuco *via* Pata, Province of Caupolican, Republic of Bolivia.

Peltura sp.

Two specimens of *Peltura* were obtained in soft, pale-violet or purple shales in this locality. The beds clearly belong to the Upper Cambrian, and are probably on the horizon of the Dolgelly Beds or Upper *Lingula*-Flags.

(2) Large blocks of sandstone (not *in situ*) about a mile from Apolo, Province of Caupolican, in a direction a little west of north.

Symphysurus Apolonista, sp. nov. and *Trinucleus boliviensis*, sp. nov.

[1] 'Ueber primordiale & untersilurische Fossilien aus der Argentinischen Republik' Palæontographica, Suppl. iii, Lief. 2 (1876) pp. 5 *et seqq.* See also 'Beiträge zur Kenntniss einiger paläozoischen Faunen Süd-Amerikas' Zeitschr. Deutsch. Geol. Gesellsch. vol. xlix (1897) pp. 274–317 & pls. vii–xii; and I. Thomas, 'Neue Beiträge zur Kenntniss der devonischen Fauna Argentiniens' *ibid.* vol. lvii (1905) pp. 233–90 & pls. xi–xiv.

[2] 'Paläozoische Versteinerungen aus Bolivien' Neues Jahrb. Beilage-Band viii (1893) pp. 5–114 & pls. i–v.

[3] 'As Trilobitas do Grez de Ereré e Maecurú, Estado do Pará, Brazil' Rev. Mus. Nac. Rio de Janeiro, vol. i, 1895 [1895 on title-page; 1896 on coloured wrapper]. Published separately in 1890.

[4] Most of the places referred to here will be found in the map accompanying Dr. Evans's paper on his 'Expedition to Caupolican, Bolivia, 1901–1902' Geogr. Journ. vol. xxii (1903) pp. 601–42.

" The specimens occur in a light-coloured friable sandstone. *Trinucleus* is confined to the Ordovician System, while *Symphysurus* is limited to the Tremadoc and Arenig Series. The sandstone is, therefore, probably of Arenig age. Both species occur in the same blocks; and it may be observed that *Trinucleus boliviensis* resembles *Tr. coscinorhinus*, Ang., which seems to be the only species of *Trinucleus* in Sweden that extends downwards into beds with *Symphysurus*.

(3) Right bank of the River Caca, between the mouth of the River Challana and that of the Coroico, Province of Caupolican.

Ogygia sp.

The only trilobites from this locality being fragments of *Ogygia*, all that it is possible to say is that the beds are Ordovician, and probably belong to the lower part of that system.

(4) Nodules found lying loose on the ground, on the track from Apolo to San José de Chupiamónas, rather more than 3 miles north-north-east of Apolo, Province of Caupolican.

Phacops cf. *arbuteus*, Lake; *Dalmanites Paitúna*, Hartt & Rathbun (?); and *D. Maecurúa*, J. M. Clarke (?).

Phacops arbuteus occurs in the Bokkeveld Beds of Cape Colony; *Dalmanites Paitúna* and *D. Maecurúa* in the Devonian strata of Brazil. The nodules are, therefore, clearly of Devonian age, and probably belong to the Lower Devonian.

(5) Found by Mr. John Turle on the Puerto-Mapiri and Aten road, between Achicheri and Aten (probably near the River Yuyo), on the borders of the provinces of Caupolican and Muñecas.

Dalmanites sp.

Only a single broken specimen was obtained from this locality. It appears to be allied to *Dalmanites Maecurúa*, Clarke, or to *D. Clarkei*, Ulrich; and the beds are probably Devonian.

Description of the Species.

PELTURA sp. (Pl. XL, fig. 1.)

Two specimens of the thorax of this form have been found in pale-violet or purple shale from above Pata. The more perfect shows twelve segments; the axis is broad, forming about one-third of the total width, and there are slight indications of a median tubercle on some of the rings; the pleuræ are horizontal, at right angles to the axis, deeply grooved, obliquely truncate, and produced into very short points.

On the same specimen the outline of the free cheek is also partly visible. It was crescentic, with the genal angles completely rounded, and the eye placed far forward.

The width of the thoracic axis and the shape of the free cheek, render it almost certain that the specimens belong to the genus *Peltura*. The remains are not sufficient, however, for specific description.

Locality (1). Three miles north-east of Pata.

SYMPHYSURUS APOLONISTA,[1] sp. nov. (Pl. XL, figs. 2 & 3.)

Head semicircular, very convex, forming nearly a quarter of a sphere. Glabella smooth, not elevated, occupying about one-third of the whole width of the head, and reaching forward to the anterior margin; the axial furrows which define the glabella are well-marked, they converge gently forwards until within a short distance of the anterior margin, where they again diverge and at the same time become slightly shallower. Occipital furrow well defined, both on the glabella and on the cheeks. Eyes fairly large, prominent, placed very close to the glabella, and about half way between the frontal and posterior margins. Facial suture in front of the eye indistinct, but appearing to run nearly parallel to the axial furrows; behind the eye, it is deflected outwards and meets the posterior margin within the genal angle. The genal angle was apparently rounded, the cheeks not marginate.

The tail is highly convex; it appears to have been nearly semicircular, and not marginate. Axis conical, raised, reaching to the posterior margin, where it terminates in a blunt point; it bears a number of annulations, but (probably in part on account of the nature of the matrix) these are too indistinct to be counted. The lateral lobes are smooth.

This form is not unlike *Symphysurus incipiens*, Brögger[2]; but the greatest constriction of the glabella is more forward than in that species, the eyes are smaller, and the tail was apparently not marginate. As regards the last character, however, there is room for doubt, since the only specimen of the tail is obviously incomplete.

Locality (2). About a mile north-by-west of Apolo.

TRINUCLEUS BOLIVIENSIS, sp. nov. (Pl. XL, figs. 4 & 5.)

Only the head of this little species is known, and in outline it forms a segment of a circle. Glabella pyriform, narrow posteriorly, broad in front, very convex and prominent, standing high above the level of the cheeks; anteriorly it ends abruptly and almost vertically at the fringe, upon which it does not encroach; two pairs of short glabellar furrows near the base; occipital furrow deep. Cheeks triangular, slightly convex, with deep occipital and marginal furrows. Fringe very narrow, and nearly uniform in width throughout: owing to the coarseness of the material in which the specimens are preserved, the structure of the fringe is not distinct, but in one or two cases traces of the perforations are visible.

[1] *Apolonista* = an inhabitant of Apolo, common gender. The name was kindly suggested to me by Dr. Evans.

[2] 'Die Silurischen Etagen 2 & 3' Christiania 1882. p. 58 & pl. i, figs. 1 & 2.

The genus *Trinucleus* appears to be new to South America. Prof. Kayser[1] has described and figured several remains of *Ampyx* from Potrero de los Angulos in the Argentine Republic; but, with this exception, no representative even of the family, so far as I am aware, has hitherto been recorded from South America.

In its narrow fringe and convex pyriform glabella, *Trinucleus coscinorhinus*, Ang., from the *Chasmops*-Limestone of Sweden, somewhat resembles the species just described; but in the former the glabella is not so prominent, and it is much more constricted towards its base.

Locality (2). About a mile north-by-west of Apolo.

OGYGIA sp. (Pl. XL, figs. 6 & 7.)

From the third locality, on the River Caca, came a number of fragments of tails. These were subtriangular in outline, with a very broad and well-defined margin, and must have attained a length of three-quarters of an inch. Axis narrow, reaching to the margin, and, so far as can be seen, without annulations. Lateral lobes but slightly arched, marked by faint ribs which are sometimes obsolete.

From the same locality comes a small hypostome, about as broad as it is long, ending in an obtuse point; a strong curved furrow passes transversely across, a little within the distal margin, and a second short furrow seems to cut off the extreme point.

To judge from the tails alone, the species might belong to either *Niobe* or *Ogygia*, or even to the genus *Asaphus*. But the hypostome seems to be distinctly the hypostome of an *Ogygia*; and it closely resembles that of *Ogygia Selwyni*, Salter.

Prof. Kayser[2] has already described and figured the tail of an *Ogygia* from Argentina, and he draws attention to its resemblance to *O. Selwyni*, Salter.

Locality (3). River Caca.

PHACOPS cf. ARBUTEUS, Lake. (Pl. XL, fig. 8.)

1904. *Phacops arbuteus*, Lake, 'The Trilobites of the Bokkeveld Beds' Ann. S. A. Mus. vol. iv, p. 203 & pl. xxiv, figs. 2–4.

Of this form only a single specimen, showing the central portion of the head, has been found. The glabella is elongated, nearly parallel-sided, rounded in front, and decidedly convex transversely; it bears a number of scattered tubercles. The anterior pair of glabellar furrows is strongly inclined forwards, and is quite distinct; the second pair is not so clear, but this is apparently due to the imperfection of the specimen; the third pair is much the strongest of the three and is nearly at right angles to the axis. The frontal lobe of the glabella is very long, forming about one half of the

[1] 'Primordiale & untersilurische Fossilien aus der Argentinischen Republik' Palæontographica, Suppl. iii, Lief. 2 (1876) p. 24 & pl. i, figs. 25–27.

[2] *Ibid.* p. 12 & pl. i, fig. 20 [*non* pl. ii, as stated on that page].

whole. The occipital furrow is deep, and the occipital segment bore a strong spine, of which only the basal portion is preserved.

So far as the state of the Bolivian and South African specimens allows comparison, the resemblance of this form to *Ph. arbuteus* is practically complete. The glabella is perhaps more nearly parallel-sided, and the first two pairs of glabellar furrows are somewhat less distinct.

Dalmanites gemellus, Clarke, is similar in some respects, but the glabella is not elongated, and the frontal lobe is short.

Locality (4). Three miles north-north-east of Apolo.

DALMANITES PAITÚNA, Hartt & Rathbun (?). (Pl. XL, figs. 9 & 10.)

1875. *Dalmania Paitúna*. C. F. Hartt & R. Rathbun. 'On the Devonian Trilobites & Mollusks of Ereré' Ann. Lyc. Nat. Hist. N. Y. vol. xi (1876) p. 111.

1890. *Dalmanites (Cryphæus) Paitúna*, J. M. Clarke, 'Trilobitas do Grez de Ereré e Maecurú' Rev. Mus. Nac. Rio de Janeiro, vol. i, p. 39 & pl. i, figs. 13–14, 16–17.

1903. *Dalmanites (Cryphæus) Paitúna*, F. Katzer, 'Geologie des unteren Amazonasgebietes' p. 212 & pl. xv, figs. 11 *a*–11 *b*.

Two small and imperfect heads seem to belong to this species.

Locality (4). Three miles north-north-east of Apolo.

DALMANITES MAECURÚA, J. M. Clarke (?) (Pl. XL, fig. 11.)

1890. *Dalmanites Maecurúa*, J. M. Clarke, 'Trilobitas do Grez de Ereré e Maecurú' Rev. Mus. Nac. Rio de Janeiro, vol. i, p. 23 & pl. ii, figs. 1–3, 6–7, 10, 15.

1903. *Dalmanites Maecurúa*, F. Katzer, 'Geologie des unteren Amazonasgebietes' p. 212 & pl. xv, figs. 12 *a*–12 *d*.

A fragmentary specimen enclosed in a nodule shows the basal portion of the glabella, the free cheek, and part of the thorax. Both glabella and free cheek agree, so far as they go, with Dr. Clarke's figures.

Locality (4). Three miles north-north-east of Apolo.

DALMANITES sp.

A very fragmentary specimen, in dark shale, shows the axis and part of the right lateral lobe of a tail, which is probably referable to the genus *Dalmanites*. There is a general resemblance to *Dalmanites Maecurúa*, Clarke, and *D. Clarkei*, Ulrich [1]; but only ten annulations are visible on the axis and on the lateral lobe, and the worn condition of the specimen prevents any closer comparison.

Locality (5). Between Achicheri and Aten.

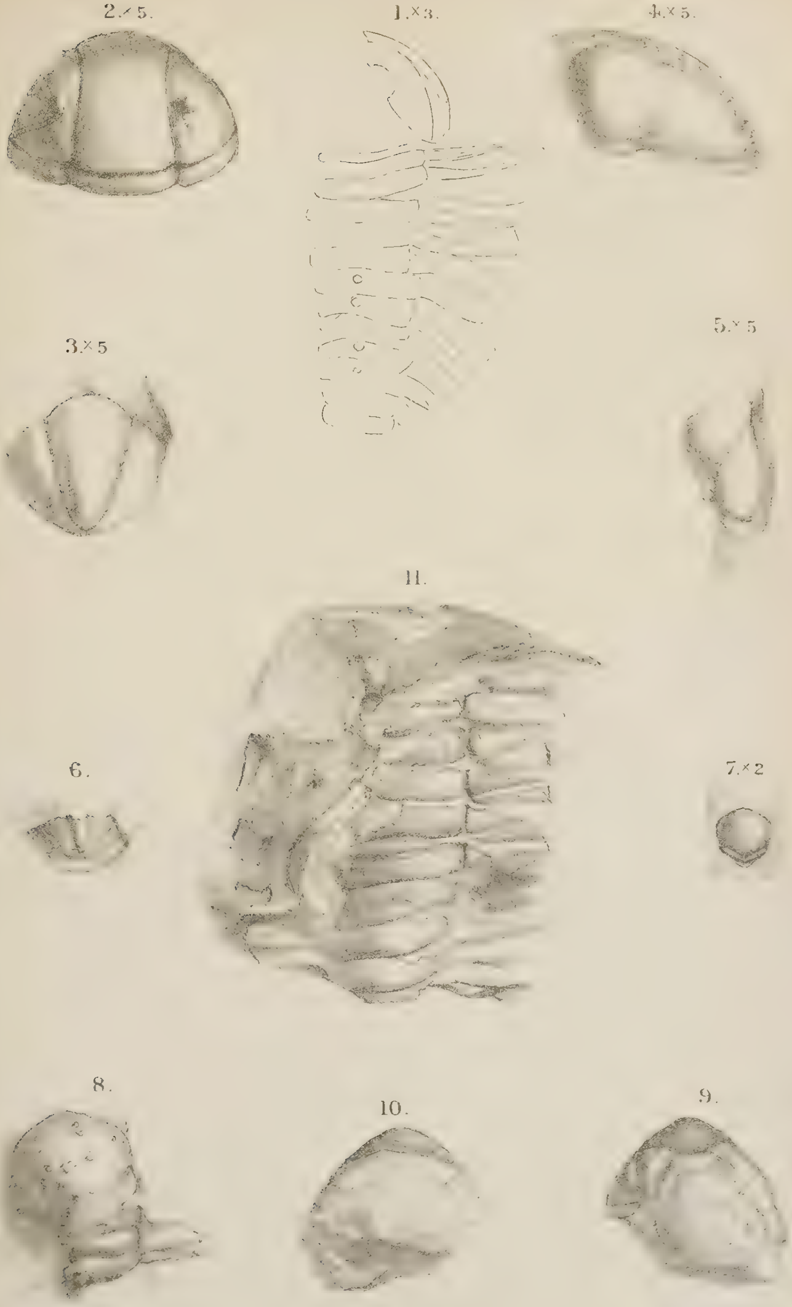
[1] Neues Jahrb. Beilage-Band viii (1893) p. 19 & pl. i, fig. 13.

EXPLANATION OF PLATE XL.

[The specimens have been placed by Dr. J. W. Evans in the British Museum (Natural History) at South Kensington.]

Fig. 1. *Peltura* sp. Natural size.
2. *Symphysurus Apolonista*, sp. nov., head. × 5.
3. *Symphysurus Apolonista*, sp. nov., tail. × 5.
4. *Trinucleus boliviensis*, sp. nov., head. × 5.
5. *Trinucleus boliviensis*, sp. nov., side view of head. × 5.
6. *Ogygia* sp., fragment of tail. Natural size.
7. *Ogygia* sp., hypostome. × 2.
8. *Phacops* cf. *arbuteus*, Lake, portion of head. Natural size.
9. *Dalmanites Paitúna*, Hartt & Rathbun (?), head. Natural size.
10. *Dalmanites Paitúna*, Hartt & Rathbun (?), reflexed frontal border of head, seen from below. Natural size.
11. *Dalmanites Maecurúa*, J. M. Clarke (?). Natural size.

[For the Discussion, see p. 432.]



T. H. Michael del. et lith.

Bale & Danielsson, L^td imp

TRILOBITES FROM BOLIVIA.

17. *On* Graptolites *from* Bolivia, *collected by* Dr. J. W. Evans *in* 1901–1902. By Ethel M. R. Wood, D.Sc. (Communicated by Dr. J. W. Evans, LL.B., F.G.S. Read April 25th, 1906.)

The graptolites collected by Dr. John W. Evans from Bolivia, and sent to me for inspection, are marked as coming from five separate localities.

The best-preserved forms occur in black pyritic shales exposed at 'a halting-place on the right bank of the Rio Coranhuata, known as Culi, on the up-stream side of the Puente de Culi (J. 28/4/02).' The rock is cleaved, and the graptolites are in consequence somewhat distorted, but the well-known species *Didymograptus bifidus*, Hall, is recognizable. Associated with this abundant form there is one small fragment of a slender extensiform *Didymograptus*, apparently of the type of *D. affinis*, Nich., but too fragmentary to admit of specific identification.

Black shales occurring at another locality 'on the left bank of the Rio Coranhuata, on the down-stream side of the Puente de Culi (H. 28/4/02),' are crowded with graptolites, but unfortunately much distorted and in a poor state of preservation.

On one slab from this spot several examples of a species of *Phyllograptus* are recognizable, and one of *Glossograptus*. The commonest graptolitic form present, however, is one which it is difficult to assign to any known genus or species. It belongs to the family of the Diplograptidæ, and possesses three conspicuous spines at its proximal extremity together with a long virgula distally produced. It is, perhaps, most closely allied to the genus *Cryptograptus*; but all details as to the form of the thecæ are obscure, and the specimens are too distorted to allow of description.

Another slab from the same locality shows, in addition to this *Cryptograptus* (?), fragments of what appear to be a *Didymograptus* of the '*bifidus*'-type.

Somewhat softer black pyritic shales obtained from 'the left bank of the Rio Coranhuata on the up-stream side of the Puente de Paracorin, and on the down-stream side of the Rio de Paracorin (G. 28/4/02),' show examples of *Didymograptus bifidus*, fragments of a *Didymograptus* of the '*Nicholsoni*'-type, together with an indeterminable species of *Diplograptus*.

So far, therefore, as one can judge from the meagre graptolitic evidence available, all these Bolivian black shales occupy approximately the same horizon, corresponding to the upper part of the Arenig formation of Great Britain. The genus *Phyllograptus* is, so far as known, restricted to the Arenig; and *Didymograptus bifidus*, which has a world-wide distribution, is everywhere characteristic of its highest zone (Lower Llanvirn of Hicks).

A different type of Bolivian graptolite-bearing rock is met with on the 'hill-slope on the right bank of the Rio de Amantala, on the up-stream side of the Raqui-raqui and the down-stream side of the Rio de Sant' Iago.' It is a laminated shale, extremely soft, and of a pale silky-grey colour, weathering to a dull orange-red tint. It

shows graptolites, but these are rare; they are preserved as reddish-brown films, and are somewhat distorted. The only form present is a species of *Climacograptus*, which may be compared with *Cl. confertus*, Lapw. If this identification be correct, then the horizon occupied by these pale shales is practically the same as that of the black shales already noticed (namely, Upper Arenig); but the evidence, as it stands, is insufficient to settle this point.

A similar rock obtained from 'the hill-top known as Pilone, between Huanai and Tipuani,' yields an indeterminable fragment of a Dichograptid.

The specimens have been placed by Dr. Evans in the British Museum (Natural History), South Kensington.

Discussion (on the two foregoing Papers).

The Chairman (Dr. J. E. Marr) asked whether any of the graptolites were found in the beds containing some of the trilobites. The Author of one of the papers had stated that the Devonian trilobites were more related to those of South Africa and North America than to those of Northern Europe. He therefore asked whether they bore any resemblance to those of the Devonian beds of Bohemia.

Dr. J. W. Evans briefly described the localities from which the specimens were obtained. He stated that the differences in characters between the black and the pale Arenig shales appeared to be due to the lateritization of the latter.

Mr. J. Hopkinson said that the specimens of graptolites exhibited were very badly preserved, and therefore difficult to determine; but *Didymograptus bifidus*, a typical Upper Arenig species, was easily recognizable. From the presence of *Phyllograptus* he thought that the rocks might extend below the Upper Arenig. The pale shale was very like that found in contact with trap-rocks (greenstone) in the Middle Arenig of St. David's (South Wales), where it contained graptolites, and appeared to be merely the black shale baked.

Mr. G. W. Lamplugh, commenting on the wide interest of the correlation, remarked that, as the Bokkeveld Beds contained the oldest marine fauna yet discovered in South Africa, no comparison of the South American fossils with the earlier faunas of this region was possible, and the correlation with the European equivalents was therefore necessarily substituted. It was permissible to believe that, if the earlier faunas of the South African region were known, they would show an equally-close agreement with the South American fossils.

Mr. Philip Lake said that, so far as the trilobites were concerned, the Devonian faunas of South Africa and South America were more closely related to each other than to that of Bohemia. He thought it very likely that, when Cambrian and Ordovician trilobites were discovered in South Africa, they would be found to resemble those of Europe. The differentiation of the Devonian faunas was probably due to a redistribution of land and sea.

18. Brachiopod Homœomorphy : *Pygope*, *Antinomia*, *Pygites*.

By S. S. Buckman, F.G.S. (Read March 21st, 1906.)

[Plate XLI.]

To be able to arrange, in the Geological Department of the British Museum (Natural History), the species known as *Terebratula diphya* and *T. diphyoides*, with their allies, it was necessary to ascertain the generic and specific names which such shells should bear. The following remarks are partly the results of such enquiries, partly of investigations carried on at other times in connexion with other collections. The work has led to finding certain overlooked specific designations, while there seem to be disclosed not only notable cases of homœomorphy, but an interesting course of Brachiopod evolution.

To deal with the specific synonymy :—The name *diphya*, Colonna, is pre-Linnean, and therefore cannot remain. The first post-Linnean designation for some of the shells in question is given by Bruguière in 1792 [3].[1] He named and figured a non-perforate shell *Terebratula pileus* (p. 424), and a perforate one *T. cor* (p. 425).[2] These figures, with others of *Terebratulæ* were reproduced in the 'Encyclopédie Méthodique' [4], being drawn under Bruguière's direction, as he states in the 'Journal d'Histoire Naturelle' p. 419. They were published in 1797 [33], without any names, and were accompanied by figures of another perforate *diphya*-like fossil.

In 1819, Valenciennes [36] wrote the articles on the *Terebratulæ* in Lamarck's 'Animaux sans Vertèbres' : he named the last-mentioned fossil (Ency. Méth. pl. ccxl, fig. 4) *Terebratula deltoidea* ; to the reproduced figures of Bruguière's *T. pileus* (Ency. Méth. pl. ccxli, fig. 1) he gave the name *T. triangulus* ; and the reproduced figures of Bruguière's *T. cor* he left without appellation. But Valenciennes uses the term *T. cor* for another species, saying nothing about Bruguière's prior use of it. Valenciennes's *T. cor* has been identified by Davidson as a Lias shell [13] ; but this use of the name must drop.

It is singular to find that in so few years Bruguière's paper in the 'Journal d'Histoire Naturelle' had been apparently forgotten, his name *T. pileus* overlooked, and his name *T. cor* misused. It is more remarkable to find that the paper has been overlooked ever since. It is not mentioned by Suess [34], who wrote a treatise on these species and gave an otherwise very full synonymy ; it is not noticed by Pictet, who monographed the *diphya*-like forms ; and its title does not appear in Davidson & Dalton's Bibliography [16].

[1] Numerals in square brackets throughout this paper refer to the Bibliography on p. 451.

[2] The work in which these are figured was kindly brought to my notice by Mr. B. B. Woodward, F.L.S., in connexion with an investigation into the first post-Linnean use of the term *Terebratula*. I owe him my best thanks for this and much other help.

Meanwhile, prior to Valenciennes, another author, James Parkinson, had in 1811 figured two *diphya*-like shells [28]: he named them both *Terebratulites triquetra*, but one is perforate, the other is imperforate—the latter seems to be the same as Bruguière's *T. pileus*.

The next author to be considered is Catullo [7]. He figured various perforate forms and an imperforate fossil under the name *Terebratula antinomia*; but as he only mentions the perforate forms in his description, one of them must be taken as the type. The identification of Catullo's species is important; because it was on these figures of Catullo that Link, in 1830, founded the genus *Pygope* [24]. Little doubt but that the perforate character was considered the essential feature of the genus; and therefore one of Catullo's perforate shells must be taken as the type of *Pygope*. Catullo subsequently wrote a paper [8] to show that his *T. antinomia* was different from *T. deltoidea*, Val. (Lamarck). This paper is not noticed in Suess's synonymy [34], nor in Davidson's Bibliography [16]. But what Catullo figures in this case as *T. antinomia* is a different specimen from any of the perforate examples which he figured before by that name; he himself admits this. And as it does not agree with his former figures in shape, one may conclude that it is specifically distinct. For the present, it is necessary to distinguish it as *T. antinomia 4*. His imperforate form he now names *T. mutica*. Later still, Catullo entered into more detail [9]: he again figured *T. antinomia* and *T. mutica*; he also copied from the Encyclopédie Méthodique the figure of *T. deltoidea*, Valenciennes (Lamarck), and the figure of *Anomia diphya* from Colonna.

A further paper by Catullo [10] is important, as, in it (p. 74), he proposed the generic name *Antinomia* for perforate Terebratulids. He drops the term *antinomia* as a trivial name; but he shows five species in outline-drawings—*Antinomia diphya* and *A. deltoidea*, which he assigns to the Neocomian; *A. angulata*, *A. angusta*, and *A. dilatata*, which he places in the 'Epiolitic Limestone,' say, Upper Jurassic. He says nothing about how these species agree with his previously-named forms; but the outline of *A. diphya* is evidently taken from Colonna's figure, and that of *A. deltoidea* from either the Encyclopédie Méthodique, or from Catullo's previous reproduction thereof: only, it is reduced to one-half linear.

These facts may be summarized as follows:—

The syntypes of *Terebratula antinomia*, Catullo, are the specimens depicted in his figures *p*, *q*, *r*, *s*, *t* [7].

The specimen represented in fig. *q* was subsequently eliminated by Catullo himself [8].

Three specimens thus remain—represented as *p*, *r*, and *s* + *t*.

The genosyntypes of *Pygope*, Link, are the specimens represented by Catullo's figures *p*, *q*, *r* [7].

Of these, *p* and *r* are perforate, and *q* an imperforate species.

The genosyntypes of *Antimonia*, Catullo, are the species to which that author gave the names *A. diphya* (von Buch), *A. deltoidea* (Val.), *A. angulata*, *A. dilatata*, and *A. angusta* [10].

The above are the facts: they admit of varied interpretation. For instance, the type of *Terebratula antinomia* may be selected out of four specimens. Then the genotype of *Pygope* may be selected from at least two species; and it is not necessary that what is selected to be the type of *T. antinomia* be taken to be the genotype of *Pygope*. In fact, in view of Catullo's generic use of the term *Antinomia*, it seems desirable to avoid this; which is possible, as there are five species out of which to select the genotype of *Antinomia*.

From among several attempted methods of arrangement, the following seems to give the most satisfactory results in the circumstances—diminishing as much as possible the difficulty of identifying Catullo's most indifferent figures:—

To select as the type of *T. antinomia* the specimen of which two figures are given, namely Catullo's *s*, *t* [7]. To select as the type of *Pygope* Catullo's fig. *r*; this figure shows the perforation somewhat distant from the umbo. On this account, and because of its shape, I identify this figure with Valenciennes's *Terebratula deltoidea* [36].

Then, out of the five species assigned to *Antinomia* by Catullo, one, *A. deltoidea*, would consequently be withdrawn; another, *A. diphya*, is almost unrecognizable; the same remark applies to *A. angulata*. There remain then two species, *A. angusta* and *A. dilatata*. The latter is a very definite form, though Catullo has exaggerated its angles; and I select it as the type of *Antinomia*, believing it to be the same species as that which Catullo originally called *Terebratula antinomia*, fig. *r* [7]. Hence, if this identification be correct, the proper designation of the type of the genus will be *Antinomia antinomia* (Catullo); although it must be remembered that the genolectotype of *Antinomia* must be stated as *Antinomia dilatata*, Catullo = *T. antinomia*, Catullo.

From the statement of facts given above, it will be noticed that the text-books and other systematic works are quite incorrect in giving *Terebratula diphya* as the type of the genus *Pygope*. This has arisen from the idea that Colonna's name overrode all others applied to the perforate Terebratulids, and that the name *diphya* was sufficient to cover all or most of the species of such perforate shells. Whatever view be taken of the number of species necessary, the following statements at any rate are justified:—

That *T. diphya* as a post-Linnean designation has not priority over any names applied to perforate Terebratulids before 1835.

That *T. diphya* is not mentioned as a species of the genus *Pygope* by the founder of the genus: he knows only *T. antinomia*.

That *T. cor*, Bruguière, is the first post-Linnean designation for a perforate Terebratulid.

That when writers give the type of a genus, they should quote the actual designation of the species referred to by the author of the genus, not their interpretation of it, however certain they may feel.

If it be asked why two generic names, *Antinomia* and *Pygope*, should be necessary, the answer is—the evidence seems to show that, used in the manner just set forth, these names designate two genetic series, in which, remarkable as it may seem, the peculiar perforate shape has really been developed independently twice over. There are characters running through the species of each series, such as the size and position of the perforation, the shape of the side and the curvature or otherwise of its margin, which enable the morphic equivalents of the two series to be separated.

Nor does this fully state the case. There is actually another line of these perforate Terebratulids, and this has a special character of its own separating it from *Pygope*, though in other respects it is similar. It seems, therefore, that the perforate character—or rather the growth of two large lobes and their ultimate junction—has actually been developed three times over, and that such development took place at three closely-successive dates about the end of the Jurassic and beginning of the Cretaceous Period.

Before enlarging on this subject, it may be well to notice certain other species of these perforate Terebratulids which have received names.

One species has been generally overlooked, in fact I have found only a solitary reference to it. It is the *Terebratula Duvali*, Newman, named by him in the 'Zoologist' in 1844 [25]. I interpret this species as being a *Pygope*, and a near ally of *T. deltoidea*.

A very remarkable species, with a large perforation, is the Neocomian shell to which A. d'Orbigny gave the name *T. diphyoides* [27]. I take as the type of his species the specimen which he considered an adult form (pl. dix, figs. 6, 7, 8, & 9). Since the other forms which he figures are not ontogenetic stages (as he supposed), but represent the different phyletic stages in the progressive development of a perforate Terebratulid from a Glossothyridoid, it is important to select one particular form as the type.

Another species to be compared with this one, showing its character of large perforation, is *Terebratula janitor*, Pictet [29]. This name again is applied to a series of forms similar to those called *T. diphyoides*; that is to say, it denotes a series of phyletic stages. But there is a distinction running through the series *T. diphyoides* which separates it from the series *T. janitor*; namely, that in the ventral valve from the beak to the perforation there is a sulcus:—that is to say, in the stage which is the morphic representative of the Glossothyridoid ancestor, in the *T.-diphyoides* series there is a sulcus in the ventral as well as in the dorsal valve[1]; but in the *T.-janitor* series there is not this ventral sulcus, nor is it present in *Antinomia*. Apparently then the *T.-diphyoides* and the *T.-janitor* series represent forms developed along somewhat parallel but independent lines. Either the glossothyridoid ancestor of the former series developed into a *T.-Euthymi* stage (Pl. XLI, fig. 17)—

[1] A corresponding fold within the dorsal sulcus accompanies the development of the ventral sulcus.

the stage of ventral sulcus added—before the lobate stage was commenced; or the *Terebratula-janitor*-series, if it had such an ancestor, has managed to lose all trace of this ventral-sulcus stage which the *T. diphyoides* retains so markedly.

In order to distinguish the *diphyoides*-series of genetic forms, I propose to use de Haan's MS. name *Pygites*. I do this, because *T. janitor* belongs to the same series as *T. deltoidea*, that is to say it is a *Pygope*. In both these species there is no dorsal sulcus in the preperforate stage; and yet their perforation is larger and more anteriorly situated than in *Antinomia*.

Thus there would appear to have been, from a Glossothyridoid form, three independent lines of development into bifidate and perforate stages (see p. 438).

The forms of the different stages in the three developmental lines are thus distinguishable:—

Glossothyridoid Stage.

Antinomia. Transverse shape.
Pygope. Very transverse.
Pygites. Very transverse, develops dorsal fold and ventral sulcus.

Bifidate Stage.

Antinomia. Division of lobes carried close to umbo. Lobes long, not very wide. Side flattened, and margin much curved.
Pygope. Division of lobes not so near umbo. Lobes wide, not very long. Side more or less acute; margin straight.
Pygites. Like *Pygope*, but with an extra fold and furrow in the preperforate stage.

Perforate Stage.

Antinomia. Perforation small and close to umbo. Sides flattened; margin much curved.
Pygope. Perforation large, and somewhat distant from umbo. Sides subacute; margin straight.
Pygites. Like *Pygope*, but with extra fold and furrow.

As to the fold and furrow, Pictet says [29, p. 164]:—

'It [*T. janitor* s.l. = *Pygope*] is distinguished very clearly [from *T. diphyoides* s.l. = *Pygites*] by . . . . its dorsal [ventral] ridge being completely destitute of furrows, and by the absence of a median ridge on the base of the small valve. I have had in my hands at least 60 examples, which, compared with my 200 specimens of *diphyoides*, have never furnished any case of transition or of doubt.'

Pictet may also be consulted with advantage as to the general features which separate 'the species with small perforation' [*Antinomia*] from the *janitor-diphyoides* forms. The development of these three genetic series through these three stages may be followed in Pl. XLI, and may be stated somewhat as follows:—

Antinomia is descended from a rather transverse *Glossothyris*-like form, which took on compression of the lateral margin

(glossothyridoid stage). Next, it developed the two long side-lobes (bifidate stage, *T.-sima* stage). The space between the lobes was deep, carried near to the umbo, but the lobes were not parted so very widely. When, later, the lobes fused (perforate stage) there was produced a series of forms with a small perforation fairly close to the umbo.

On the other hand, *Pygope* arose from a considerably transverse Glossothyridoid. This developed broad side-lobes, with a relatively-broad, not deep, parting (bifidate stage); but it did not carry the division so near to the umbo as *Antinomia*. Consequently, when coalescence of the lobes took place, the resulting perforation was larger, and farther from the umbo than in *Antinomia*. Then the *T.-diphyoides* series (*Pygites*) arose from a transverse Glossothyridoid, like *Pygope* did; but before attaining the bifidate stage this Glossothyridoid developed further—it began plicating. It raised a fold in the dorsal sulcus, and made a furrow in the ridge of the ventral valve. It thus produced a plicate form analogous to *Terebratula Euthymi*, Pictet, only it was much more transverse. Then it carried out the development of the bifidate and perforate stages parallel to those of *Antinomia* and *Pygope*; but it kept, like *Pygope*, a relatively-large perforation. Both *Pygites* and *Pygope* are distinguished from *Antinomia* by lacking the flattened sides and the curved side-margin.

In estimating the size of the perforation, morphic equivalents should always be compared.

The development of the diphyoids from glossothyridoid to bifidate, to perforate stages is very obvious; but what succeeds to the perforate stage? The question seems to be answered by a remarkable species figured by Zeuschner, for which I propose a name, *Pygope solidescens* (see p. 447). In this species the perforation is closed—there remains, as it were, only the scar of the wound; while the line of junction of the coalesced lobes seems to have completely disappeared.

This suggests, extraordinary as it seems, that such species as *T. pileus*, Brug. (= *T. triangulus*, Val.), *T. euganeensis*, Pictet—in fact, the imperforate forms—are the further development; that they have actually lost all trace of the perforation and of the line of coalescence, and show no trace of ever having been perforate Terebratulids. What is more remarkable, and shows the cycle in which development so often moves, *T. pileus* is actually again sulcating the dorsal valve, and recommencing a glossothyridoid stage.

I must confess that I was quite unprepared for the idea that imperforate *T. pileus* could have been developed from perforate forms—not until I saw the *Pygope solidescens*. The discovery of that species I owe to the chance sending of a volume from the Society's Library, and therefore tender my best thanks to our courteous Assistant-Librarian, Mr. W. R. Jones.

In view of this result, an interesting surmise suggests itself. There is in the Middle Lias a Glossothyridoid (*T. Aspasia*, Meneghini) (Pl. XLI, fig. 23), with sulcate dorsal valve, a form just analogous to

the glossothyridoid ancestor of the perforate Terebratulids; in fact, authors have called it *Pygope Aspasia*.[1] There is in the Upper Lias an imperforate *Terebratula* (*T. erbaensis*, Suess) (Pl. XLI, fig. 24), so like the imperforate *diphya*-forms that Suess himself at one time called it *T. diphya*, and it has figured in literature as *Pygope erbaensis*. Have we here the first and last (the glossothyridoid and *pileus* or imperforate) stages in the development of a series of forms analogous to *Antinomia* and *Pygope*, but of such series no perforate species have yet been found? Or did *Terebratula Aspasia* develop into *T. erbaensis* without going through a pronounced bifidate stage (*sima*-stage)? At any rate, the relation of *T. pileus* to the perforate and the glossothyridoid forms seems to show that, in spite of their dissimilarity, *T. erbaensis* may possibly be the more or less remote development of *T. Aspasia*, connected by a greater or less series of bifidate and perforate forms.

The geological position of the diphyoids is much removed from that of *T. erbaensis* and *T. Aspasia*. Pictet [29] says:—

'This species [*T. janitor* s.l. = *Pygope*] is generally characteristic of the deposits that lie on the borders of the Jurassic and Cretaceous Periods. It [*Pygope*] probably somewhat preceded *diphyoides* [*Pygites*]; but is, on the other hand, later than the species with small perforation [*Antinomia*]' (p. 164).

Of these Cretaceo-Jurassic strata and their zonal divisions a good exposition is given by Prof. Haug [22], from which I can adapt the following Table (I) to explain the position and sequence of the diphyoids.

TABLE I.—STRATA YIELDING DIPHYOIDS (ADAPTED FROM E. HAUG).

NEOCOMIAN.		VALANGINIAN.	
PORTLANDIAN.	UPPER. Upper Volgian.	Zone of *Hoplites Boissieri*. Berriasian.[2]	Koniakau Beds.[3]
		Zone of *Hoplites Calisto*.	Stramberg Beds.
	LOWER. Lower Volgian.	Zone of *Perisphinctes contiguus*.	Upper *Diphya*-Kalk.
		Zone of *Oppelia lithographica*.	Lower *Diphya*-Kalk.

[1] This rare species can be added to our British fauna. A specimen was found by the late Edward Wilson, F.G.S., in the Junction-Bed [Middle Lias], Thorncombe Beacon, near Bridport (Dorset).

[2] Kilian [23] p. 430, says that Berriasian = Lower Valanginian, and should be retained in the Cretaceous System.

[3] Pictet [29] p. 165, says that 'the limestone of Koniakau is identical with that of Stramberg.'

From Pictet [29] pp. 155, 156, and from other authors, it is possible to gather the distribution of diphyoids into the various strata—Berriasian, Stramberg Beds, and *Diphya*-Kalk; but, though useful, this is not sufficiently exact for zoological purposes. For instance, we cannot say which, if any forms, distinguish the Upper from the Lower *Diphya*-Kalk; but the wide and incorrect use of the term *Terebratula diphya* is perhaps responsible for that.

Then from Pictet [29] p. 309, it may be learnt that these diphyoid-yielding strata are divisible into some eight or nine beds, one of which alone is 1500 feet thick. It is obvious, therefore, that such a bed as the *Diphya*-Kalk, wherein are found species of *Antinomia* in various stages of development, must have taken a long enough time in deposition to allow of the evolutionary changes required.

The following Table (II) shows the sequence of the diphyoids, so far as I can interpret the records of various authorities:—

TABLE II.—STRATIGRAPHICAL SEQUENCE OF DIPHYOIDS, ACCORDING TO THE INFORMATION GIVEN BY PICTET AND OTHER AUTHORS.

NEOCOMIAN, BERRIASIAN.	*Pygites diphyoides*; *Pygites*, bifidate forms; *Pygope Duvali*; *P. subtriangulata*; *P. euganeensis*; *Antinomia equicampestris*.
STRAMBERG BEDS.	*Pygope janitor*; *P. deltoidea*; *P. Duvali (?)*; *P. (?) misilmerensis*. *Pygope*, bifidate forms are from Koniakau. [Pictet, p. 165.]
KLIPPENKALK, Red Ammonite-Limestone, Upper & Lower *Diphya*-Kalk.	*Antinomia angusta*, Upper *Diphya*-Kalk. *Pygope (?) diphya*, *P. (?) solidescens*, *P. (?) rectangularis*, *P. rupicola*; *Antinomia planulata*, *A. sima*, *A. diphora*, *A. dilatata*, *A. Catulli*, *A. cor*, *A. Quenstedti*, *A. triquetra*, *A. pileus*.

The geographical distribution of the diphyoids is essentially circum-Mediterranean—that is, the southern parts of Europe, and Northern Africa.

The following are a few references to nomenclature and synonymy—not by any means exhaustive, it is true, but sufficient (it may be hoped) to be a guidance for future work.[1] For one reason exhaustiveness could not be aimed at, because one of the most important works on this subject has been inaccessible: there is no copy in the British Museum (Natural History), and I have not heard of one anywhere else, of the important work by Zeuschner [38]. Further against exhaustiveness is the fact that many forms of *Pygope* and *Pygites*—those in the bifidate stage for instance—

[1] For assistance in this study my thanks are due to my eldest daughter, who traced and pasted on slips for comparison nearly 250 figures of these fossils.

possess no trivial names by which they can be referred to. Therefore in the works noticed in the Bibliography (p. 451) are many figures of diphyoid forms not mentioned in the following pages.

Genus Antinomia, Catullo, 1851.

Genosyntypes—*A. diphya*, *A. deltoidea*, *A. angulata*, *A. dilatata*, *A. angusta.*
Genolectotype—*A. dilatata*, Catullo = *Terebratula antinomia*, Catullo.

A series of diphyoid Terebratulids in which the perforation (when present) is small and set close to the umbo, while the sides of the valves are flattened, and the side-margin is much curved.

Glossothyridoid Stage.

Antinomia planulata (Zeuschner). (Pl. XLI, fig. 1.)

Terebratula planulata, Zeuschner, 1846, *teste* Zittel. *T. planulata*;[1] Zittel, 1870, pl. xiv (xxxviii) figs. 3, 4, 5. *T. diphyoides*; Quenstedt, 1871, pl. xlvii, figs. 121 & 122. *T. diphoros*; Quenstedt, 1871, pl. xlviii, fig. 1.

According to Zittel, this form has been named *T. planulata* by Zeuschner in the work which is not obtainable.

This form, which is more transverse than *Glossothyris nucleata*, shows a similar deep sulcus in the anterior part of the dorsal valve, giving the front margin a linguiform appearance. The arrest of growth in the linguiform portion, and the expansion of the lobes on each side of it, produce the bifidate form.

Bifidate or Binate Stage.[2]

Antinomia sima (Zeuschner) 1846, *teste* Pictet. (Pl. XLI. fig. 2.)

Terebratula sima, Zeuschner, 1846 (Pictet). *T. sima*; Pictet, 1867, pl. xxxiii, figs. 4 & 5 only. *T. sima*; Zittel, 1870, pl. xiii (xxxvii) figs. 11 & 12.

A form with long lobes, and a remarkable curved side-margin.

Antinomia diphora (Zeuschner) 1846, *teste* Quenstedt. (Pl. XLI, fig. 3.)

Terebratula diphoros, Zeuschner, 1846 (*teste* Quenstedt). *T. diphya*; Pictet, 1867, pl. xxxi, fig. 8. *T. diphoros*; Quenstedt, 1871, pl. xlviii, fig. 6 only.

Whether this is really Zeuschner's species is doubtful, nor can it be said if Pictet's form agrees with what Quenstedt calls *diphoros*, because the latter shows no side view. What Pictet shows differs from *A. sima* by its less curved margin.

According to Pictet and Quenstedt the following other species were named by Zeuschner :—*T. rogoznicensis*, *T. axine*, *T. expansa*, and *T. Staszicii*; and it seems that all except the last one are bifidate forms.

[1] When the author cited is the giver of the trivial name a comma is used; when he is not, a semicolon.

[2] A leaf with two lobes is known in botany as 'binate' (*folium binatum*).

Antinomia sp. *a*. (Pl. XLI, fig. 4.)

Terebratula diphya; Pictet, 1867, pl. xxxi, fig. 7.

This form has the two lobes nearly in contact, and is the transition-stage between the bifidate and perforate species. Possibly Zeuschner has given it a name.

Perforate Stage.

Triangulate.

The four following species show four forms ranging from wide- to narrow-angled. The first three show much-curved side-margins; about that of the last there is no information.

In these and other forms the characters of the vascular markings might repay careful attention. In specimens that I have examined there seems to be much difference in their size, number, and approximation.

Antinomia antinomia (Catullo).

Terebratula antinomia, Catullo, 1827, pl. v, figs. *s* & *t* only.

It is assumed that Catullo's very poor figures are intended to represent a specimen of the next species.

Antinomia dilatata, Catullo, 1851. (Pl. XLI, fig. 5.)

Antinomia dilatata, Catullo, 1851. *Terebratula diphya*; Suess, 1852, pl. xxxi, figs. 13–15. *T. dilatata*, Pictet, 1867, pl. xxxii, fig. 4. *T. Catulloi*, Pictet, 1867, page 202 (*pars*).

The latangulate form.

Note.—It is assumed that in Catullo's sketch the spread of the lateral angles has been exaggerated.

Antinomia Catulli (Pictet) 1867.

Terebratula antinomia, Catullo, 1829 & 1840, non Cat. 1827. *T. diphya*; S. P. Woodward, 1853. *T. diphya*; Davidson, Mon. Introd. 1854, pl. vi, fig. 3, fig. reduced? *T. dilatata*, Pictet, 1867, pl. xxxii, fig. 1 (type), pl. xxxii, fig. 5, & pl. xxxii, fig. 3 (xxxiii, 2?). *T. Catulloi*, Pictet, 1867, p. 202 (*pars*).

Narrower than the last.

Note.—A species with the vascular markings very approximate and very strong. These characters are well shown by a specimen in the British Museum (Nat. Hist.), B. 8688.

Antinomia cor (Bruguière). (Pl. XLI, fig. 6.)

Terebratula cor, Bruguière, 1792. *Terebratula* . . . . . . Ency. Méth. 1797, pl. ccxl, fig. 6. *Terebratula dilatata*; Pictet, 1867, pl. xxxii, fig. 2 (pl. xxxii, fig. 5?). *T. Catulloi*, Pictet (*pars*). *Pygope diphya*; Schuchert, 1896.

This is the oldest named post-Linnean species of perforate Terebratulids. It is narrower than *A. Catulli*, as that species is now defined.

A specimen in the British Museum (Nat. Hist.), B. 16470, identifiable with this species, has the vascular markings widely separate and feeble.

ANTINOMIA ANGUSTA, Catullo, 1851. (Pl. XLI, fig. 7.)

Antinomia angusta, Catullo. *Terebratula dilatata*; Pictet, pl. xxxii, fig. 5 [6],[1] not 5 *a*, 5 *b*. *T. angusta*; Pictet, p. 202 (*pars*). *T. diphya*; Quenstedt, 1871, pl. xlvii, fig. 123.

A species from the Upper *Diphya*-Kalk (Pictet [29] p. 175).

Subtriangulate.

ANTINOMIA QUENSTEDTI, nom. nov.

Terebratula diphya; Quenstedt, 1871, pl. xlvii, fig. 115 (type). *Pygope triquetra*; Douvillé, 1880, p. 268.

A well-marked form, similar to *A. Catulli*, but smaller and stouter. Evidently it did not attain so large a size, for it shows the gerontic feature of thickened margin at a stage when *A. Catulli* is still growing normally.

There is a specimen in the British Museum (Nat. Hist.), B. 188, so exactly agreeing with Quenstedt's figures that I deem it desirable to give the form a name. Another example there (B. 8687) is a little smaller, but has an almost equally thickened margin.

Suboblong.

ANTINOMIA sp. *β*.

Terebratula dilatata; Pictet, 1867, pl. xxxiii, fig. 3.

Note.—A narrow form, but not triangulate like *A. angusta*, being nearly as broad posteriorly as anteriorly. Side-margin well curved.

Securiform=shaped like a battle-axe.

ANTINOMIA TRIQUETRA (Parkinson).

Terebratulites triquetra, Parkinson, 1811, fig. 4 only. *Terebratula antinomia*, Catullo, 1827, pl. v, fig. *p* only.

Parkinson's figure shows a form with wing-like expansions making a battle-axe shape. Catullo's is similar, but with less pronounced wings. Neither figure gives sufficient details for exact determination.

A specimen in the British Museum, No. 231, exactly agrees with Parkinson's figure and shows the battle-axe shape well. Its margin is but slightly curved, though much indented.

ANTINOMIA cf. TRIQUETRA (Parkinson). (Pl. XLI, fig. 9.)

Terebratula diphya; Pictet, 1867, pl. xxxi, fig. 2.

This form has the battle-axe shape like *A. triquetra*, but is narrower posteriorly and more produced anteriorly. A specimen

[1] Fig. 6 in text, misnumbered in plate.

similar to Pictet's is in the British Museum. No. 81055. It has an almost straight side-margin, while the vascular markings are widely separate and feeble.

Subobcordate.

ANTINOMIA ANGULATA, Catullo.

Antinomia angulata, Catullo, 1851, p. 75. ? *Terebratula diphya*; Quenstedt, 1871, pl. xlvii, fig. 123.

Nothing seems to agree with Catullo's figure. It is said to be one-half of the natural size; if so, the specimen must have been far larger than any others—quite a giant.

I can only suggest that Catullo's figure is intended to represent a form like that of Quenstedt, pl. xlvii, fig. 123. This shares with Catullo's a peculiarity which separates it from most other forms—the sides (anterior part) run convex, not concave, to make the angles; anteriorly the sides converge, instead of diverging.

Imperforate Stage.

Triangulate.

ANTINOMIA PILEUS (Bruguière) 1792. (Pl. XLI, fig. 8.)

Terebratula pileus, Brug. 1792. *Terebratula* . . . . . Ency. Méth. 1797, pl. ccxli, fig. 1. *T. triquetra*, Parkinson, 1811, fig. 8. *T. triangulus*, Valenciennes in Lamarck, 1819. *T. antinomia*, Catullo, 1827, pl. v, fig. *q*; *T. mutica*, Catullo, 1829. *T. triangulus*; von Buch, 1838, copy of Ency. Méth. *T. diphya*; Suess, 1852, pl. xxxi, figs. 16 & 17. *T. triangulus*; Quenstedt, 1871, pl. xlviii, figs. 9 & 10. *T. triangulus*; Pictet, 1867, pl. xxxiv, figs. (1 ?) 2, 3.

This is the species which has so long been known as *Terebratula triangulus* [Valenciennes in] Lamarck; but Bruguière's name *T. pileus*, which has been quite overlooked, is nearly 30 years older, and therefore takes precedence.

In the British Museum (Nat. Hist.) are two good examples (B. 8686; B. 15031), and there are other imperfect specimens.

It may be that, under this name, I have combined what are really imperforate forms of more than one series; for some figures and specimens show a nearly straight margin, but in Bruguière's figure it is distinctly curved.

I have not been able to detect in any examples the least sign of a scar, or of irregularity of growth-lines such as would be expected.

ANTINOMIA EQUICAMPESTRIS (Guembel).

Terebratula equicampestris, Guembel, 1861, p. 563 (description only).

This is, from the description, presumably an *Antinomia* like *A. pileus* in general form, and having the peculiar, laterally-flattened, even furrowed, side-margin. The coarse, distant growth-ridges would separate the species from *A. pileus*; but this character is seen in *Terebratula euganeensis*, a species which has not the flattened side-margin.

Genus Pygope, Link.

Genosyntypes—*Terebratula antinomia*, Catullo, 1827, p. 169 & pl. v, figs. *p*, *q*, & *r*.
Genolectotype—*Terebratula antinomia*, Catullo, *ibid.* fig. *r* = *T. deltoidea*, Valenciennes.

A series of diphyoid Terebratulids in which the perforation (when present) is relatively larger and farther removed from the umbo than that of *Antinomia*; while the sides of the valves are not compressed, and the side-margin is practically straight.

Glossothyridoid Stage.

Pygope rupicola, Zittel.

Terebratula rupicola, Zittel, 1870, pl. xiv (xxxviii) figs. 1 & 2.

Similar to *Antinomia planulata*, but broader, as one would expect this stage in *Pygope* to be.

Bifidate Stage.

Bifidate forms, morphic equivalents of *A. sima* and *A. diphora*, are to be seen in Pictet [29], pl. xxx, figs. 5–6 & 9–10, and Suess [35], pl. vii (iii) fig. 13; see also Pl. XLI, fig. 10. Forms with the two wings just coming into contact—the next stage—are shown by Pictet, pl. xxix, figs. 4 & 6; see Pl. XLI, fig. 11.

For other figures of *Pygope*, besides those mentioned here or later, see Pictet, *Terebratula janitor*; Glocker [19], *T. diphya*, pl. xxxv, fig. 14; and Gemmellaro [18], pl. i, figs. 1–5.

Perforate Stage.

Pygope janitor (Pictet) 1867. (Pl. XLI, fig. 12.)

Terebratula janitor, Pictet, 1867, pl. xxx [fig. 2*bis*] lectotype; pl. xxx, fig. 1 ?

Remarks.—As I do not feel able to separate what Pictet calls his type-form from the earlier-named *Terebratula deltoidea*, and as another of Pictet's forms is occupied by *T. Duvali*, an overlooked name, it becomes necessary to fall back on one of Pictet's varieties. If his name is to be preserved, that must be taken as a lectotype. It is a latangulate form, morphic equivalent of *Antinomia dilatata*.

Pygope deltoidea (Valenciennes) 1819. (Pl. XLI, fig. 13.)

Terebratula ——, Ency. Méth. 1797, pl. ccxl, fig. 4. *T. deltoidea*, Val. in Lamarck, 1819. *T. antinomia*, Catullo, 1827, pl. v, fig. 2. *T. diphya*, von Buch, 1838 (copy of Ency. Méth.). *T. diphya*; Bronn, 'Leth. Geogn.' 1838, pl. xxx, fig. 14 (copy of Ency. Méth. ?). *T. deltoidea*; Catullo, 1840 (copy of Ency. Méth.). *Antinomia deltoidea*; Catullo, 1851 (outline; reduced ½ after Ency. Méth.). *Terebratula janitor*, Pictet, 1867, pl. xxix, fig. 5. *T. diphyoides*; Quenstedt, 1871, pl. xlviii, fig. 1.

The specimen which Davidson figured in the 'Annals' [13] as *T. deltoidea* (pl. xiii, fig. 20) does not seem to be the same shell as

that depicted in the Encyclopédie Méthodique. Davidson's practice with regard to these types was very unfortunate. He says:—

'There is . . . some difficulty in a few cases of defining which were Lamarck's real types, as several specimens of different species are sometimes placed on one tablet . . . . it is possible that some of the specimens now in B. Delessert's hands many have been displaced while in the possession of Prince Massena . . . I must . . . add that, in some few cases the specimens belonging to Lamarck's collection were in bad condition, which I have restored in the figures from well-preserved specimens of the identical species in my own collection, in order to prevent misconceptions as to the shells intended as types.' (*Op. cit.* p. 434.)

He not only restored, but he sometimes depicted quite other specimens. The result is the very opposite to what he intended—misconception as to what are Lamarck's (Valenciennes's) types is increased instead of prevented.

PYGOPE DUVALI (Newman) 1844. (Pl. XLI, fig. 14.)

Terebratula diphya; Pusch, 1837. *T. Duvallii*, Newman, 1844, figs. *a*, *b*, *c* (lectotype), fig. *d?* Cf. *T. janitor*, Pictet, 1867, pl. xxx, fig. 3. *T. diphyoides*; Quenstedt, 1871, pl. xlvii, fig. 117 only.

I obtained this reference from J. E. Gray's Catalogue [20]. Newman's paper seems to have escaped notice otherwise; its title does not appear in Davidson & Dalton's Bibliography.

The species was obtained from Grasse in the South of France, a well-known Neocomian locality.

A specimen in the British Museum, B. 10355, is similar to Newman's figures *a*, *b*, & *c*, but smaller, and has a much larger perforation. This agrees better with *Pygope*, for Newman's delineation of it seems rather too small. This specimen is from Wadi Sabella, Algiers.

Pictet's figures in pls. xxxiii, fig. 1, xxxi, fig. 6, xxxi, fig. 4, show a series roughly parallel to the series *Antinomia dilatata*—*A. angusta*. But Pictet's forms differ from these by having a straight side-margin. On the other hand, they do not seem to belong to *Pygope*, as the perforation is situated more posteriorly, and the side-margin is recessed. Compare also the form shown by Zittel, 1870, '*T. diphya*' pl. xiii (xxxvii) fig. 1. Its straight margin distinguishes it from the *A. dilatata*-series; its sunken margin, etc. from *Pygope*.

Perforate Stage.

Securiform=shaped like a battle-axe.

PYGOPE (?) DIPHYA (von Buch) 1835.

Anomia diphya, Colonna, 1606. *Terebratula diphya*, L. von Buch, 1835, pl. i, fig. 12 (a reproduction of Colonna's figure). *T. diphya*; Catullo, 1840, and *Antinomia diphya*; Catullo, 1851 (reproductions of the same). *Terebratula diphya*; Pictet, 1867, pl. xxxi, fig. 3, and pl. xxxi, fig. 1?

Notes.—The name can only date from L. von Buch's use of it; and his drawing is insufficient for exact work. It seems desirable to

take one of Pictet's figures as the neotype. The battle-axe shape is suggested in Colonna's figure; it is shown to perfection in Pictet's pl. xxxi, fig. 1. This character and the practically straight side-margin separate the species from *Antinomia*; but I do not feel certain that this species really belongs to *Pygope*—that is, that it is a development of *Pygope deltoidea*.

Subperforate.

PYGOPE (?) SOLIDESCENS, nom. nov. (Pl. XLI, fig. 15.)

1870. *Terebratula triangulus*; Zeuschner [39] (*non* Valenciennes) pl. vii, figs. 5–7.

It is necessary to name this species for the sake of reference: the name chosen signifies the closing-up of a wound, which the obsolescence of the perforation seems to suggest.

Concerning the specimen which he figures, Zeuschner says:—

'L. von Buch has correctly united *T. triangulus* with *T. diphya*: interesting evidence for that opinion is found in the specimen from Kijow. The perforate [ventral] valve is not entirely smooth, as is the case with the ordinary *T. triangulus*, but, in the upper half, is seen the commencement of a hole, and from it to the anterior end runs a small sinus [sulcus]. This hole has an appearance like that shown by *T. dilatata*; Pictet, Mél. Pal. pl. xxxii, fig. 3 *a*; but it does not pierce both valves, and is barely 4 mm. deep. In the imperforate [dorsal] valve there is, in the place mentioned, only an insignificant deepening surrounded by several small depressions.' (*Op. cit.* p. 270.)

An important point to be noticed about Zeuschner's specimen is that its anterior end is not swallow-tailed, as is the case with the *Antinomia dilatata-angusta* series: instead it projects forward in half-moonshape. Now, one would certainly expect any specimen connecting the perforate and imperforate stages of either *Antinomia* or *Pygope* to show a swallow-tailed anterior end—some trace of the manner in which the two lobes fused. One would have expected this specimen of Zeuschner's to show an anterior notch, quite as much as a trace of the perforation.

The horizon from which this specimen of Zeuschner's came is important. He says that it was found on the southern slopes of the Tatra, in the village of Kijow in the Zips.

According to Pictet [29] p. 309, there are at the Tatra, at least, strata from about Portlandian to Neocomian; and Zeuschner seems to suggest that this specimen came from the same formation as the Klippenkalk [Portlandian] which yields the ordinary *Terebratula triangulus* [*Antinomia pileus*], with which he compares his specimen. Seeing, however, that *T. erbaensis* was once confounded with *T. diphya*, and supposed to come from the same formation, the matrix being so similar, but was afterwards discovered to be an Upper-Lias shell, it may be suggested that with Zeuschner's specimen there has possibly been a similar error. But it would be most remarkable if, in a series which has as yet yielded no examples of the perforate stage, this subperforate form were found; while, in the diphyoids,

where the perforate stages are so extraordinarily represented, there should be no example of the stage connecting perforate and imperforate. It is sufficiently remarkable, in any case, that there is only this one subperforate example. But, whatever the horizon of this specimen, it does show the connexion between perforate and imperforate stages: it is most important evidence for that.

Since the above was written I have seen in the British Museum a specimen, B. 10824, 'from the north flank of Tatra, R. I. Murchison Collection.' It is a fragment of a diphyoid embedded in matrix.

Imperforate Stage.

Triangulate.

PYGOPE (?) MISILMERENSIS (Gemmellaro).

Terebratula misilmerensis, Gemmellaro, 1871, pl. i, figs. 6 & 7.

This is a rather thick form, and has a half-moon front, the same character as is noticeable in *P. solidescens*. Gemmellaro's claim that the form is distinct from *Antinomia pileus* (*Terebratula triangulus*) seems to be quite justifiable. It is from the *T. janitor*-beds of Sicily.

PYGOPE (?) SUBTRIANGULATA (Guembel).

Terebratula subtriangulata, Guembel, 1861, p. 563. *T. euganeensis*, Pictet, 1867, pl. xxxiv, fig. 7 only.

Remarks.—Guembel's name precedes Pictet's. His description, unaccompanied by a figure, seems to indicate such a form as Pictet has figured as *T. euganeensis* (pl. xxxiv, fig. 7), a more massive and less triangulate species than his other forms of this name. Guembel says that his species comes from the Middle Neocomian.

PYGOPE (?) EUGANEENSIS, Pictet. (Pl. XLI, fig. 16.)

Terebratula euganeensis, Pictet, 1867, pl. xxxiv, figs. 5 (take as type) & 6 (5, 6, 'échantillons typiques' Pictet, p. 183). ?*T. triangulus*; Quenstedt, 1871, pl. xlviii, fig. 11 (*not* 9, 10).

Pictet says that this is a Neocomian species.

Quadrangulate.

PYGOPE (?) RECTANGULARIS (Pictet) 1867.

Terebratula rectangularis, Pictet, 1867.

Note.—Distinct from *Antinomia pileus* (Brug.) not only by its shape, but because its side-margin is straight, not curved, and subacute. Pictet says that this species comes from the Red Ammonite-Limestone [Portlandian]; this is against its being a descendant of *Terebratula janitor*: it is difficult to say to what series it belongs.

Genus PYGITES, gen. nov., *ex* de Haan, MS.[1]

1833. *Pugites*, de Haan, MS. Mus. Lugdun., *teste* Bronn [2], Dall [12], *et al.* Genotype—*Terebratula diphyoides*, d'Orbigny.

A series of diphyoid Terebratuloids with the characters of *Pygope*, except that in the preperforate stage (onto- and phylogenetic) the dorsal valve carries an additional fold, and the ventral valve an additional sulcus.

Remarks.—De Haan's name is practically a *nomen nudum*. It can take no priority; but there is no question of that. The evidence shows that he applied it as the generic appellation for diphyoid Terebratulids; and when he gave it, also for long afterwards, all such diphyoid Terebratulids were lumped under the name *Terebratula diphya*. As a name now seems necessary for an unoccupied series of diphyoid Terebratuloids, and as there is this name in print, it appears desirable to employ it. From the various diphyoid Terebratuloids which it would have covered, one is now selected to be the genotype, namely, *Terebratula diphyoides*, d'Orb.

For forms in the bifidate stage, see d'Orbigny, pl. dix, figs. 3 & 4; and Pictet, pl. xxiv, figs. 15 & 16 (see Pl. XLI, fig. 18). Morphic equivalent of *A. dilatata* is Pictet, pl. xxiv, fig. 11; of *A. Catulli*, Pictet, pl. xxiv, fig. 13; of *A. cor*, Pictet, pl. xxiv, fig. 12; and of *A. angusta*, Pictet, pl. xxiii, fig. 2 (see Pl. XLI, figs. 20, 21). A remarkably transverse form with very rounded angles is Pictet's pl. xxiii, fig. 7. All these forms are named *T. diphyoides*, but they represent various stages of phylogenetic development. The size of the perforation, the plain, straight side-margin, and generally the rounded-off angles distinguish these forms from their morphic equivalents in *Antinomia*. The dorsal fold and the ventral sulcus of the preperforate stage distinguish them from *Pygope*.

For other figures of *Pygites* see Ooster [26], pl. v, figs. 1–3, 4?

PYGITES DIPHYOIDES (d'Orbigny). (Pl. XLI, fig. 19.)

Terebratula diphyoides, d'Orbigny, 1851, pl. dix, figs. 6–9 only. *Id.*, Pictet, 1867, pl. xxiii, figs. 4, 5, 6, 8; & pl. xxiv, fig. 14. *Id.*, Davidson, 1869.

Remarks.—Davidson figures the loop of this species [14].

A series of *Pygites* spp. decreasing in size and angularity are shown in Pl. XLI, figs. 20–22.

As a conclusion to these observations on the diphyoids I would append a few remarks:—(1) Upon some Jurassic Terebratuloids which show analogous stages of development; and (2) upon an analogous case of successive independent development of like forms among a certain group of Ammonites: the history of their nomenclature forms a most instructive parallel to the case of the diphyoids.

[1] For subsequent quotation of MS. names, whether generic or trivial, I suggest this practice—that the name of the giver of the MS. appellation be hyphened to that of the describer, so as to give to the first his due—the latter name indicates where the description may be found. Thus this name would be subsequently quoted as 'Haan-Buckman.'

(1) Analogous Stages among some Terebratuloids.

Glossothyridoid Stage.—Notable representatives of this stage of development may be seen in *Glossothyris nucleata* and *G. hippopus*, in *Pseudoglossothyris curvifrons* and others; in *Aulacothyris* spp. var.; in *Orthotoma*. Some specimens of *G. nucleata* and of *Aulacothyris Haasi*, S. Buckm., show the commencement of the next stage.

Plicated Glossothyridoid Stage (*T. Euthymi*-stage).—A species which attains to the beginning of this stage is *Pseudoglossothyris galeiformis* (M'Coy); and one of the stocks of the so-called *Aulacothyris* which attains this stage is made a genus, *Antiptychina*, Zittel. Then *Dictyothyris coarctata* shows the full development of the stage—allusion is only made to its shape, not to its ornament.

Bifidate and Perforate Stages.—Outside the diphyoids there seems to be no development quite analogous to these. There is a checking of growth in the median lobe and a protrusion of the side-lobes, making bilobate forms, and this is, of course, a commencement of the bifidate stage. But further than that there seems to be no development. Of this bifidate stage, *Zeilleria* spp. var. may be cited as examples, and perhaps *Z. cornuta* as a notable case. The stage may also be noted in *Cincta*, and in a few Terebratulæ, my *T. imitator*, for example. This bilobate character is generally regarded as one of the special generic features of *Zeilleria*, so that the bilobate long-looped Terebratuloids are called by that generic name. But this is only a stage of development at which independent long-looped stocks arrive. *Zeilleria*, like *Aulacothyris*, is polygenetic; and to obtain a true classification on genetic lines, it is necessary to recognize that at present these genera only indicate the stages of development—the Glossothyridoid and the Bilobate—of many different stocks. To distinguish between these stocks other characters will have to be taken into account.

Imperforate Stage.—Of other Terebratuloids in this stage there is no evidence, because there is none of their having come through a perforate stage; but attention may be directed to a form curiously like *Antinomia pileus*: it is termed '*Waldheimia bilobata*, Stoppani' by Zittel [40]; and it has even the reflected anterior margin—the beginning of a sulcate stage as shown in *A. pileus*. '*Waldheimia bilobata*, Stoppani' is from the Upper Lias of Luera, Lombardy.

(2) Successive Development of similar Ammonites.

I desire to draw attention to a case of successive independent development of like forms among Ammonites—first, because it parallels the development among the diphyoids; secondly, because the nomenclature-history is instructive. I refer to the Jurassic Ammonites with knotted keel. There are two groups of these—a Middle Lias (Pliensbachian) and Oxfordian. The Pliensbachian group is in two series—the *Ammonites-margaritatus* set succeeded by the *A. spinatus* forms. The Oxfordian group appears at three

successive horizons: *A. Lamberti*, *A. cordatus*, *A. alternans*, typify the three successive series of forms. Till recently all these, with some other homœomorphs which lacked the knotted keel, such as *A. oxynotus*, *A. fissilobatus*, *A. Truellii*, were placed in one genus, *Amaltheus*. Now it is recognized that these various forms belong to different genetic series, and that the Pliensbachian and Oxfordian groups belong to widely-different families. The genetic series have received different generic names: *margaritatus* is *Amaltheus*; *spinatus*, *Paltopleuroceras*; *Lamberti*, *Quenstedtoceras*; *cordatus*, *Cardioceras*; *alternans*, *Amœboceras*; while of the homœomorphous forms, *oxynotus* is *Oxynotoceras*, a degenerate Arietan; *fissilobatus* is a phylogerontic *Sonninia*; and *Truellii* is *Strigoceras*, of the family Oppelidæ. And further, in each of these various genera many species are recognized, although once it was freely argued that some of these different genera were but varieties of a single species.

The separation into genera of the similar forms of diphyoid Terebratuloids is quite in accordance with this precedent. What was the generic grouping of the knotted-keeled Ammonites 20 or 30 years ago is the position of the diphyoids to-day. What is the generic grouping of those Ammonites to-day may be expected to be parallel to the grouping of the diphyoids in the future. So that the present generic grouping of those Ammonites may be regarded as the prefiguration of what the diphyoid grouping will be.

Bibliography.

1. 1838. Bronn, H. G. 'Lethæa Geognostica' vol. ii.
2. 1848–49. Bronn, H. G. 'Index Palæontologicus' p. 1059.
3. 1792. Bruguière, J. G. 'Sur deux nouvelles Espèces de Térébratules fossiles.' Choix des Mémoires sur divers Objets d'Hist. Nat., formant les Collections du Journ. d'Hist. Nat. vol. i, pp. 419–27 & pl. xxii.
4. [1797] [Bruguière.] Tableau et Encyclopédie Méthodique des trois Règnes de la Nature. Vers, Coquilles, Mollusques & Polypiers (vol. ii of plates) pl. ccxl, figs. 4, 6; pl. ccxli, fig. 1.
5. 1835. Buch, L. von. 'Ueber Terebrateln' Abh. k. Akad. Wiss. Berlin für 1833, pp. 21–144 & pls. i–iii.
6. 1838. Buch, L. von. 'Essai d'une Classification & d'une Description des Térébratules' Mém. Soc. Géol. France, vol. iii. No. 6, pp. 105–78 & pls. xiii–xvi.
7. 1827. Catullo, T. A. 'Saggio di Zoologia fossile' pl. v, figs. *p*, *q*, *r*, *s*, *t*, p. 169.
8. 1829. Catullo, T. A. 'Sopra alcuni Terreni adequabili alla Formazione di Sedimento inferiore delle Provincie Austro-Venete, e sopra varie Specie fossili trovate nel Terreno di Sedimento medio' Annali di Storia Naturale (Bologna) vol. i (1829) pp. 297–318 & pl. v.
9. 1840. Catullo, T. A. 'Osservazioni Geognostico-zoologiche' Nuov. Saggi I.R. Accad. di Scienze, Lettere, ed Arti in Padova, vol. v, pp. 217–42 & pl. ii.
10. 1851. Catullo. 'On the Epiolitic Rocks of the Venetian Alps' Quart. Journ. Geol. Soc. vol. vii, pp. 66–76.
11. 1606. Colonna, F. 'Minus cognitarum Stirpium aliquot, ac etiam rariorum nostro Cœlo orientum Ἐκφρασις.' Rome, 1606.
12. 1877. Dall, W. H. 'Index to the Names .... of the Class Brachiopoda' Bull. U. S. Nat. Mus. No. 8.
13. 1850. Davidson, T. 'Notes on an Examination of Lamarck's Species of Foss. Terebratulæ' Ann. & Mag. Nat. Hist. ser. 2, vol. v, p. 437.
14. 1854. Davidson, T. 'Monogr. Brit. Foss. Brachiop.' Introduction (Palæont. Soc.).
15. 1869. Davidson, T. 'Note [to a paper by E. B. Tawney: Occurrence of *T. diphya*]' Quart. Journ. Geol. Soc. vol. xxv, pp. 308–309.

16. 1886. DAVIDSON, T., & DALTON, W. H. 'Bibliography of Brachiopoda' Monogr. Brit. Fossil Brach. vol. vi (Palæont. Soc.).
17. 1880. DOUVILLÉ, H. 'Notes sur quelques Genres de Brachiopodes' Bull. Soc. Géol. France, ser. 3, vol. vii, p. 268.
18. 1871. GEMMELLARO, G. G. 'Studj Paleontologici sulla Fauna del Calcare a *Terebratula janitor* del Nord di Sicilia' Palermo, Part iii.
19. 1845. GLOCKER, E. F. 'Bemerkungen ueber einige Terebrateln aus dem Jurakalk Mährens & Ungarns' Nova Acta Acad. Cæs.-Leop. vol. xxi, pp. 493–516 & pl. xxxv.
20. 1853. GRAY, J. E. 'Catalogue of the Mollusca in the British Museum' Part iv, Brachiopoda ancylopoda or Lamp-Shells.
21. 1861. GUEMBEL, C. W. VON. 'Geognostiche Beschreibung des bayerischen Alpengebirges und Seines Vorlandes' vol. i.
22. 1899. HAUG, E. 'Portlandien, Tithonique & Volgien' Bull. Soc. Géol. France, ser. 3, vol. xxvi, p. 217.
23. 1899. KILIAN, W. Bull. Soc. Géol. France, ser. 3, vol. xxvi, p. 430.
LAMARCK, *see* VALENCIENNES.
24. 1830. LINK, H. F. 'Handbuch der physikalischen Erdbeschreibung' vol. ii, Abh. i, p. 451.
25. 1844. NEWMAN, E. 'Note on Duval's Fossil *Terebratula*' Zoologist, vol. ii, pp. 679–80 & text-figures.
26. 1863. OOSTER, W. A. 'Pétrifications des Alpes Suisses: Brachiopodes.'
27. 1851. D'ORBIGNY, A. 'Paléontologie française: Terrains Crétacés' vol. iv (Brachiopodes) pp. 87–89 & pl. dix.
28. 1811. PARKINSON, J. 'Organic Remains, &c.' vol. iii. pl. xvi, figs. 4 & 8.
29. 1867. PICTET, F. J. 'Mélanges paléontologiques' vol. i, livr. 2, 3, & 4.
30. 1837. PUSCH, G. G. 'Polens Paläontologie.'
31. 1871. QUENSTEDT, F. A. 'Petrefacten Deutschlands, Bd. II: Die Brachiopoden.'
32. 1896. SCHUCHERT, C. 'Brachiopoda,' in Eastman's transl. of Zittel's 'Text-book of Palæontology' vol. i, p. 328.
33. 1893. SHERBORN, C. D., & B. B. WOODWARD. 'Dates of the Encyclopédie Méthodique (Zoology)' Proc. Zool. Soc. pp. 582–84.
34. 1852. SUESS, E. 'Ueber *Terebratula diphya*' Sitzungsber. Math.-nat. Classe d. k. Akad. Wissensch. Wien, vol. viii, pp. 553–66 & pl. xxxi.
35. 1858. SUESS, E. 'Brachiopoden der Stramberger Schichten' Hauer's Beiträge zur Paläontologie von Œsterreich, vol. i (2).
TAWNEY, *see* DAVIDSON.
36. 1819. VALENCIENNES, in Lamarck's 'Animaux sans Vertèbres' (article *Terebratula*), vol. vi, p. 250.
37. 1853. WOODWARD, S. P. 'Manual of the Mollusca' Part ii, pl. xv, fig. 2.
38. 1846. ZEUSCHNER. 'Nowe lub Niedokladnie opisane gatunki Skamienialosci Tatrowych odkryli opisal' Warsaw.
39. 1870. ZEUSCHNER. Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxii, pp. 269–70.
40. 1869. ZITTEL, K. A. VON. 'Geologische Beobachtungen aus den Central-Apenninen' E. W. Benecke's Geogn. Pal. Beitr. vol. ii, pp. 93–176.
41. 1870. ZITTEL, K. A. VON. 'Die Fauna der älteren Cephalopodführenden Tithonbildungen' Palæontographica, Supplem. pt. ii.

EXPLANATION OF PLATE XLI.

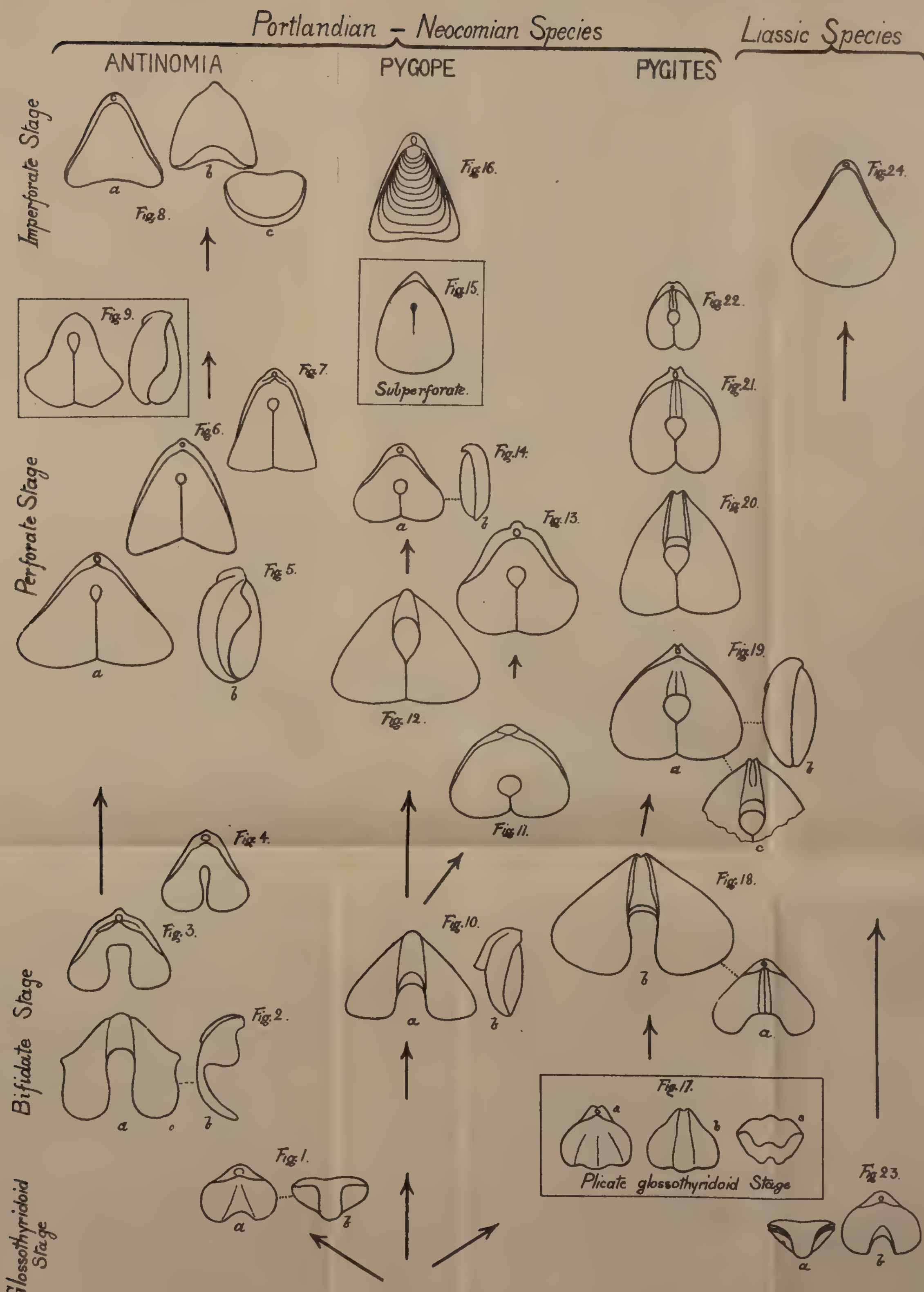
[All the figures have been reduced to one-half linear from the originals drawn by Mr. P. Highley.]

The figures are arranged in four vertical columns representing the four supposed genetic series—the columns to be read from bottom to top. The corresponding morphic equivalents in each series are to be seen by reading horizontally. Figures enclosed in rectangles do not belong to the actual genetic lines, but are illustrative of certain developmental stages.

Figs. 1–9. *Antinomia.*

Glossothyridoid Stage.

Fig. 1. *Antinomia planulata* (Zeuschner) (?), after Quenstedt's figure.—*a*, Dorsal valve, with sulcus; *b*, anterior margin, with linguiform median lobe (p. 441.)



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DEVELOPMENT OF DIPHYOIDS.

Bifidate Stage.

Fig. 2. *Antinomia sima* (Zeuschner) (Pictet), after Pictet.—*a*, Ventral valve, showing arrested median lobe and growth of lateral lobes; *b*, lateral view showing curved side-margin. (p. 441.)

3. *Antinomia diphora* (Zeuschner)?, after Pictet. (p. 441.)

4. *Antinomia* sp. *a*, after Pictet.—A form showing the lobes becoming approximate. (p. 442.)

Perforate Stage.

5. *Antinomia dilatata*, Catullo, after Pictet.—*a*, Dorsal valve; *b*, lateral view of another specimen, showing the much curved side-margin, after Suess. (p. 442.)

6. *Antinomia cor* (Bruguière), after his fig. in the Journ. d'Hist. Nat. (p. 442.)

7. *Antinomia angusta*, Catullo, after Pictet. (p. 443.)

The above three forms (figs. 5–7) are arranged obliquely, because, according to the principles of tachygenesis, it does not seem possible for the latangulate form (fig. 5), with its continued increase of expansion, to have passed into the angustangulate form (fig. 7). Nor does it seem possible for a narrow form like fig. 7 to have expanded sufficiently to produce a form like fig. 5. Perhaps the forms (figs. 5–7) are developments of a common intermediate form.

Imperforate.

8. *Antinomia pileus* (Bruguière).—*a*, Dorsal valve, after his fig. in the Journ. d'Hist. Nat.; *b*, ventral valve of another specimen (after Pictet), showing a return to the linguiform depression of the glossothyridoid stage; *c*, end-view of another specimen, dorsal valve uppermost, after Quenstedt, showing a broad linguiform depression. (p. 444.)

Perforate—Securiform.

9. *Antinomia* cf. *triquetra* (Parkinson), after Pictet.—*a*, Ventral valve; *b*, lateral view, showing a margin curved, but less so than in fig. 5 *b*. (p. 443.)

Figs. 10–16. *Pygope*.

Bifidate.

10. *Pygope* sp., after Pictet, pl. xxx, fig. 5: morphic equivalent of *Antinomia sima* and *A. diphora* (figs. 2 & 3).—*a*, Ventral valve showing latangulate form; *b*, lateral view, showing almost straight margin. (p. 445.)

Perforate.

11. *Pygope* sp., after Pictet, pl. xxix, fig. 6 *a*.—A form showing the lobes just joining up. (p. 445.)

12. *Pygope janitor*, Pictet, after his figure (pl. xxx, fig. 2 *bis*).—Dorsal valve of a latangulate form, morphic equivalent of *Antinomia dilatata* (fig. 5), but showing a remarkable difference in the size of the perforation. (p. 445.)

13. *Pygope deltoidea* (Valenciennes), after the figure in the Ency. Méth.—A form with the anterior angles rounded off. I have placed it directly above fig. 11, of which it seems to be the further direct development. It can hardly have come through *P. janitor*, fig. 12. (p. 445.)

14. *Pygope Duvali*, Newman, after his figures in the 'Zoologist.'—*a*, Dorsal valve; *b*, lateral view showing straight margin. This seems to be a sort of dwarf *P. janitor*. (p. 446.)

Subperforate Stage.

Fig. 15. *Pygope solidescens*, nom. nov., after Zeuschner.—Dorsal valve, showing a slight depression and a trace of the line of junction of the lobes. From the southern slopes of the Tatra. (p. 447.)

Imperforate.

16. *Pygope euganeensis* (Pictet), after his figure, pl. xxxiv, fig. 5.—From the Neocomian. (p. 448.)

A morphic equivalent.

17. *Terebratula Euthymi*, Pictet, after his figures in 'Mél. Pal.' livr. ii, pl. xxv, figs. 5 *a, b, d*.—This species is the morphic equivalent of the dorsally plicate, ventrally sulcate Glossothyridoid, through which *Pygites* must have come; but it is too narrow and too globose to be regarded as a true ancestor of the thin, latangulate bifidate *Pygites*. *a*, dorsal valve—the middle line indicating the fold in the sulcus; *b*, ventral valve, showing the sulcus in the ridge; *c*, anterior view, showing the above characters. From the *Diphyoides*-Limestone of Berrias. (p. 436.)

Figs. 18–22. *Pygites*.

Bifidate.

18. *Pygites* sp., after Pictet, pl. xxiv, figs. 15 & 16.—*a*, Young example, dorsal valve showing the median ridge; *b*, mature specimen, ventral valve showing the sulcus. (p. 449.)
19. *Pygites diphyoides*, d'Orb., the lectotype, after d'Orbigny.—*a*, Dorsal valve, with median ridge in the preperforate stage; *b*, lateral view, showing straight margin; *c*, portion of ventral valve. (p. 449.)
20. *Pygites* sp., after Pictet, pl. xxiv, fig. 12.—Dorsal valve, showing the sulcus. Morphic equivalent of *Antinomia cor* (fig. 6), but with a great difference in the size of the perforation. (p. 449.)
21. *Pygites* sp., after Pictet, pl. xxiii, fig. 2.—Dorsal valve, showing the median ridge. A narrow form. (p. 449.)
22. *Pygites* sp., after Pictet, pl. xxiii, fig. 1. Dorsal valve. This is a dwarf form, and is perhaps the final expression of *Pygites*. (p. 449.)

The forms (figs. 19–22) may be, unlike *Antinomia* (figs. 5–7), in direct genetic order of development: for there is a rounding-off of the anterior angles, and the relative width does not constantly increase; consequently, by tachygenesis, a narrower and narrower form would be produced.

Liassic Species.

Glossothyridoid Stage.

23. *Terebratula Aspasia*, Meneghini = *Pygope Aspasia*, auct., *Glossothyris Aspasia*, auct.; after Zittel [40], pl. xiv, fig. 1.—*a*, Dorsal valve, showing the sulcus and the sharply-reflected median linguiform lobe, seen more clearly in *b*, anterior view. (p. 438.)

This form is not only a morphic equivalent, it is also really a homœomorph of *Antinomia planulata* (fig. 1). From the Middle Lias (Pliensbachian), Cagli.

Imperforate.

24. *Terebratula erbaensis*, Suess-Pictet[1] = *T. diphya*, Suess = *T. erbaensis*, Suess MS. in Pictet = *Pygope erbaensis*, auct. After Pictet, pl. xxxiii, fig. 8 *a*.

This form may be called a homœomorph of *Antinomia* and *Pygope*, imperforate species: whether it be a morphic equivalent, whether, that is, it has passed through a perforate stage and is connected with *Terebratula Aspasia* (fig. 23), is the interesting point. (See p. 439.)

[1] See p. 449, note.

Discussion.

The Chairman (Mr. A. Strahan) regretted the absence of the Author and the cause to which it was due. The thanks of the meeting were due to Dr. Bather for the lucid exposition which he had presented in the short time available.

Dr. F. A. Bather noticed that the Author had not attempted to explain the origin of the peculiar lobation of the diphyoid Terebratulæ. Presumably it was connected with the desirability of affording more room for the respiratory arms. The tendency was constantly observable in Brachiopods, from *Orthis biloba* down to the present day ; but whether the exaggerations of it were due to a decrease in the oxygen of the water could not be decided. It was interesting to compare the perforation with the lunules in certain sea-urchins of the family Scutellidæ, where, owing to the flatness of the test, room was provided for the inter-radial internal organs by projections of the test, which ultimately met, leaving radial perforations. But the main interest of the comparison, in view of the Author's conclusions, was that this development had arisen independently in at least three genera—*Encope*, *Mellita*, and *Rotula*.

In reply to a question asked by Dr. Marr, the speaker explained that, although the general succession shown in the Author's diagram appeared to be well founded, still the precise horizons of many forms described by the older writers had not yet been definitely settled.

19. *The* Constitution *of the* Interior *of the* Earth, *as* revealed *by* Earthquakes. By Richard Dixon Oldham, F.G.S. (Read February 21st, 1906.)

I. Introductory.

Of all regions of the earth none invites speculation more than that which lies beneath our feet, and in none is speculation more dangerous; yet, apart from speculation, it is little that we can say regarding the constitution of the interior of the earth. We know, with sufficient accuracy for most purposes, its size and shape: we know that its mean density is about $5\frac{1}{2}$ times that of water, that the density must increase towards the centre, and that the temperature must be high, but beyond these facts little can be said to be known. Many theories of the earth have been propounded at different times: the central substance of the earth has been supposed to be fiery, fluid, solid, and gaseous in turn, till geologists have turned in despair from the subject, and become inclined to confine their attention to the outermost crust of the earth, leaving its centre as a playground for mathematicians.

The object of this paper is not to introduce another speculation, but to point out that the subject is, at least partly, removed from the realm of speculation into that of knowledge by the instrument of research which the modern seismograph has placed in our hands. Just as the spectroscope opened up a new astronomy by enabling the astronomer to determine some of the constituents of which distant stars are composed, so the seismograph, recording the unfelt motion of distant earthquakes, enables us to see into the earth and determine its nature with as great a certainty, up to a certain point, as if we could drive a tunnel through it and take samples of the matter passed through. The subject is yet in its infancy, and much may ultimately be expected of it; already some interesting and unexpected results have come out, which I propose to deal with in this paper.

So long ago as 1894 the late E. von Rebeur Paschwitz, recording the Japanese earthquake [1] of March 22nd, found that the record showed three separate disturbances or phases, but I believe that the true character of this threefold disturbance was not established until 1900, when I showed, [2] by a study of the available data, that the disturbance set up by a great earthquake was split up into three distinct forms of wave-motion, propagated at different rates and along different paths, giving rise to three distinct phases in its distant record. Of these, the third and latest was shown to be due to surface-waves, that is to say, wave-motion propagated along, or close to, the surface of the earth; but it was also shown that the other

[1] Peterm. Mitth. vol. xli (1895) pp. 13–21 & 39–40.
[2] Phil. Trans. Roy. Soc. ser. A, vol. cxciv (1900) pp. 135–74.

two phases, forming what are known as the preliminary tremors, represented the cropping-out of mass-waves which had travelled through the earth. It is these two phases alone with which I am at present concerned, for the third-phase waves can obviously give no information regarding the interior of the earth, as their wave-paths lie along its surface.

The researches of Dr. C. G. Knott[1] and Dr. P. Rudzki[2] have shown that no simple form of wave-motion can be transmitted through the heterogeneous rocks forming the outermost crust of the earth, and that the records from instruments situated near the origin of an earthquake cannot show any sorting-out of different kinds of wave-motion. It is only in more homogeneous material that this sorting-out can take place, and it is only at a distance of 10 degrees of arc, or about 700 miles, from the origin that the three-phase character of the record begins to appear. The waves emerging at this distance have evidently traversed more homogeneous material for a part of their course; in this part there has been a sorting-out of the forms of wave-motion into which the disturbance has been converted, and the fact that the sorting-out can be detected at so comparatively small a distance from the origin shows that the outer crust must be, comparatively, very thin. I have not been able to collect sufficient data for an accurate estimate of its thickness, but this cannot be more than about a score of miles,[3] and below it comes material of a very different character, which not only allows a sorting-out of different forms of wave-motion, but, as has been shown by Prof. Milne,[4] transmits these at a velocity much greater than is met with in the outer crust. If the figures given in the following pages do not bear out in detail his further conclusions regarding the homogeneity of the whole of the core and the rectilinear propagation of the wave-motion, this must be ascribed to the accumulation of more data than were available when he wrote. As will be seen, they are confirmed in essentials, so far as the outer six-tenths of the radius are concerned, and in the central four-tenths the first-phase waves, which alone were dealt with by Prof. Milne, are so little affected that the change might easily have escaped recognition but for the clue given by those of the second phase. It is, therefore, desirable to devote a little space to the demonstration of the reality of a distinction in kind between these two sets of waves.

In my paper quoted above, I pointed out that the different rates of propagation of the first and second phases showed that they must be referred to different forms of wave-motion, which I interpreted as being, probably, the two known forms—compressional and distortional—which can be transmitted by a homogeneous solid. As

[1] Trans. Seismol. Soc. Japan, vol. xii (1888) pp. 115–36.

[2] Beiträge zur Geophysik, vol. iii (1898) pp. 519–40.

[3] There is some, seismological, indication of a want of uniformity in this thickness, for earthquakes originating off the eastern coast of Japan exhibit a three-phase character at less distances from the origin than appears to be the case in Europe, indicating a lesser thickness of the outer crust in the former region.

[4] 'Nature' April 9th, 1903, vol. lxvii, pp. 538–39.

regards the first phase, the conclusion was only one which had already been suggested, and is still generally held; but, as regards the second, my interpretation has been traversed in two separate ways.

The first is by the Rev. O. Fisher, who, believing my interpretation to be inconsistent with his theory of the earth, has propounded a most ingenious explanation of these second-phase waves.[1] It does not seem to me that there is any insuperable incompatibility between Mr. Fisher's theory of a fluid centre and the hypothesis that the second-phase waves are distortional. We know nothing of the behaviour of matter exposed to the pressures prevailing in the interior of the earth, and it is not wholly inconceivable that a fluid under pressure of millions of atmospheres might be enabled to transmit the distortional waves which it is unable to transmit under pressures with which we are familiar. I do not, however, insist on this point, as it is immaterial to my present purpose: all that is material is that the wave-motion, in the first and second phases, differs essentially; and this is accepted by Mr. Fisher.

It is also indicated, apart from the arguments which I have already urged,[2] by the records of Prof. Vicentini's type of seismograph, composed of two heavy masses, one free to move horizontally, the other free to move vertically. In the records of great earthquakes originating at a distance of 90° of arc or more, it is found that the former gives a very small displacement for the first phase, while the latter frequently registers the maximum displacement of the whole disturbance. In the second phase the conditions are reversed, and, while the mass free to move vertically seldom gives any indication of disturbance, that which is free to move horizontally gives a very large displacement. This difference in the character of the record in the two phases shows that the movement is different, and incidentally tends to support the interpretation that I have proposed: for, if the first phase represents the outcrop of a disturbance transmitted through the earth as a condensational wave, then vertical movement would preponderate over horizontal at distances of 90° or more; while, if the second phase is caused by distortional waves, horizontal movement should preponderate in it.

This difference in the character of the records of the two phases may also be used as an argument against the idea which has been adopted in Japan,[3] that the first and second phases represent wave-motion of similar character, transmitted at different rates through layers at different depths from the surface, but in both cases parallel to, and at no great depth below, it. As this contention is incompatible with the figures given below, it need not be dealt with in this place, and the facts may be left to speak for themselves.

[1] 'On the Transmission of Earthquake-Waves through the Earth' Proc. Cambridge Phil. Soc. vol. xii (1903–1904) pp. 354–61.

[2] Phil. Trans. Roy. Soc. ser. A, vol. cxciv (1900) pp. 162–66.

[3] A. Imamura, Publications of the Earthquake-Investigation Committee in Foreign Languages, No. 16, Tokio, 1904 and later issues *passim*.

II. The Data.

In dealing with the data, it is necessary to make some selection from the large amount of material which has been collected, and to confine our attention to those records in which accuracy is *prima-facie* probable; this limits us to those earthquakes the place and time of origin of which can be determined with accuracy, and which were also of sufficient magnitude to give complete records on distant seismographs. This last reservation is necessary, for many earthquakes of great local severity are only imperfectly recorded at a distance of even a quarter of the circumference of the globe, and the portion lost is always that of the preliminary tremors.

These limitations leave only fourteen disturbances for consideration, some of which consisted of two or three distinct earthquakes, starting from the same origin at short intervals from each other. Of these, details have been published in a collected form in some cases only, in the others they are still in manuscript; but those that have been published will serve to show the manner in which scattered details are grouped and dealt with. The earthquakes utilized in this paper are:—

1. Japan, March 22nd, 1894; $10^h 22{\cdot}5^m$, $43^\circ{\cdot}0$ N., $146^\circ{\cdot}0$ E. Phil. Trans. Roy. Soc. ser. A, vol. cxciv (1900) pp. 139–40, quoting Peterm. Mitth. vol. xli (1895) pp. 14–21.
2. Argentine, Oct. 27th, 1894; $20^h 55{\cdot}5^m$, $28^\circ{\cdot}5$ S., $69^\circ{\cdot}0$ W. *Ibid.* pp. 140–142.
3. Japan, June 15th, 1895; three shocks, $10^h 31{\cdot}0^m$, $19^h 3{\cdot}2^m$, $22^h 58{\cdot}0^m$, $39^\circ{\cdot}5$ N., $144^\circ{\cdot}5$ E. *Ibid.* pp. 142–145, with some further details from Beiträge zur Geophysik, vol. vi (1903–1904) p. 408.
4. Japan, Aug. 31st, 1896; $8^h 7{\cdot}1^m$, $39^\circ{\cdot}7$ N., $140^\circ{\cdot}8$ E. *Ibid.* pp. 145–47.
5. India, June 12th, 1897; $11^h 5{\cdot}0^m$, $26^\circ{\cdot}0$ N., $91^\circ{\cdot}0$ E. *Ibid.* pp. 147–49.
6. Japan, Aug. 5th, 1897; $0^h 9{\cdot}4^m$, $39^\circ{\cdot}5$ N., $144^\circ{\cdot}5$ E. *Ibid.* pp. 149–51.
7. Turkestan, September 17th, 1897; two shocks, $15^h 28{\cdot}0^m$, $17^h 36{\cdot}0^m$, $39^\circ{\cdot}0$ N., $68^\circ{\cdot}0$ E. *Ibid.* pp. 151–55.
8. Japan, April 22nd, 1898; $23^h 34{\cdot}2^m$, $39^\circ{\cdot}5$ N., $143^\circ{\cdot}0$ E. *MS.*
9. Japan, August 9th, 1901; two shocks, $9^h 23{\cdot}5^m$ and $18^h 33{\cdot}5^m$, $40^\circ{\cdot}5$ N., $141^\circ{\cdot}5$ E. *MS.*
10. Philippines, Dec 14th, 1901; $22^h 57{\cdot}5^m$, $13^\circ{\cdot}5$ N., $121^\circ{\cdot}25$ E. *MS.*
11. Guatemala, April 19th, 1902; $2^h 22{\cdot}0^m$, $14^\circ{\cdot}5$ N., $91^\circ{\cdot}25$ W. Proc. Roy. Soc. ser. A, vol. lxxvi (1905) pp. 102–111.
12. Kashgar, August 22nd, 1902; $3^h 1{\cdot}0^m$, $39^\circ{\cdot}5$ N., $75^\circ{\cdot}9$ E. *MS.*

To which may be added two earthquakes the time of origin of which is only known by inference from distant records, as mentioned lower down:—

13. Alaska, September 4th, 1899, $0^h 20{\cdot}5^m$; September 10th, $17^h 1{\cdot}5^m$ and $21^h 39{\cdot}5^m$; about $59^\circ{\cdot}5$ N., $140^\circ{\cdot}0$ W. *MS.*
14. Ceram, September 29th, 1899, $17^h 3{\cdot}0^m$, $3^\circ{\cdot}5$ S, $128^\circ{\cdot}5$ E. *MS.*

In dealing with the records, it is necessary to bear in mind that they are liable to certain errors. In the first place, many earthquakes consist, not of a single impulse only, but of two or more, separated from each other by intervals of some minutes; and it is not uncommon for the disturbance due to the first impulse to be overlooked, either because it fails to overcome the inertia of the instrument, or because the disturbance is too small to be recognized.

Secondly the disturbance, instead of beginning abruptly, as is sometimes the case, may come in gradually: and when this is the case, it is easy for the times of commencement of each phase to vary by a minute or more, on the records of different instruments, or even in the reading of the same record by different individuals. Either of these causes will make the recorded time late, but it also happens, not commonly, though often enough for the contingency to be borne in mind, that one station or a group of stations is affected by some small local disturbance, which almost coincides with a distant earthquake, and leads to the apparent commencement being too early. Apart from these sources of error, there is also that which may easily occur in determining the time of origin of the earthquake: this will introduce an error into all the intervals, which is constant for each earthquake but varies for different ones both in amount and direction; it will, consequently, be eliminated when an average from a sufficiently-large number of earthquakes is taken, and will be partly eliminated even with the few which are at present available. The other sources of error are partly eliminated by averaging, but it is necessary to reject any records which are abnormally early or late, and to take only those which, by their close concordance with each other, show that they refer to the same phase of wave-motion. The average so obtained will naturally incline to be a little late, but is likely to be nearer the truth than any individual record, taken at random, and for this reason I shall deal, as far as possible, with averages rather than with single observations.

These averages may be obtained in two ways. In Table I (p. 472) are given all the group-averages that I have obtained · that is to say, averages of the records of groups of stations and instruments, each average being that of observations of a single earthquake, each group consisting of at least five distinct records from distances differing by less than five degrees of arc from each other.

In Table II (p. 473) a different treatment is used. The whole series of records from all earthquakes, excepting those numbered 13 and 14, were tabulated, and the average, of each group covering 5° of arc from the origin, taken. In this way we get a group of averages for each 5° from 45° to 95°, which are on the whole better than those in Table I.

For distances of 100° or over the possibility of averages is small, and I have given in Table III (p. 473) all the available records of first and second phases. The figures given are those originally determined by me, those enclosed in parentheses are times which, from their discordance with other records, were evidently misinterpreted or are otherwise doubtful.

It is evident that, having prepared these tables, we are no longer confined to the consideration of those earthquakes of which both the time and the place of origin are known; for, if the latter be known with even approximate accuracy, we can determine the former from distant records. This has enabled me to utilize two other disturbances for filling in gaps in the series of records.

The first of these disturbances is the group of earthquakes which originated in September, 1899, off the coast of Alaska. The times of origin can be determined from the records of the Italian Observatories, which lay at distances of from 73° to 81°, and the only records worth considering here are those from Cape Town, at a distance of about 150° from the origin. In all of them the commencement is almost imperceptible, and the recorded times, as compared with the times of origin, show that it was too late to represent the first phase of the original impulse, except possibly in the case of the third of these shocks, which gives an interval of 21·5 minutes. The second phase is well marked on all the records, and the times, as determined by me, on photographic copies of the original records, give intervals of 44·6, 45·7, and 45·5 minutes respectively [1]; the true interval, therefore, may be taken as about 45 minutes or a little more.

The second is the Ceram earthquake of September 29th, 1899. The place of origin of this earthquake can be fixed with a great degree of accuracy from Dr. Verbeek's description,[2] as close to 3°·5 S. lat., 128°·5 E. long. The time is not accurately known from local observatories: but the earthquake was well recorded by distant seismographs, and the records have been collected by Dr. E. Rudolph.[3] At Batavia, 22°·4 from the origin, the commencement was at 17^h $7{\cdot}3^m$, and at Calcutta, 46°·4 distant, the time was 17^h $11{\cdot}4^m$. Making the allowances indicated by Table I (p. 472), these give the time of origin as 17^h $3{\cdot}1^m$ and 17^h $3{\cdot}2^m$ respectively, which might be taken as near the true time of origin; but it will be noticed that the average-curve drawn on fig. 1 (p. 462) makes the averages just used to be about a minute and a half too early. The difference is due to one or other of the causes noticed above; and it will be better to adopt the intervals indicated by the time-curve, and accept 17^h $1{\cdot}5^m$ G.M.T. as the probable time of origin.

Accepting this as the time of origin, we get a group-average of observations from stations at distances of 103°·4 to 112°·2, the mean value being 110°·3; the mean interval for the first phase, from six records, is 17·1 minutes, and for the second phase, for ten records, is 27·3 minutes. At Cordoba (Argentina), 143° from the origin, the record as published in the British Association Seismological Circulars, gives the commencement at 17^h $21{\cdot}8^m$ and the maximum at 17^h $44{\cdot}3^m$ Greenwich time. A tracing of the record shows that this belongs to the second phase, which is well marked, and commenced about ·5 min. earlier. This gives intervals from the origin of 20·3 minutes for the first, and 42·3 minutes for the second phase.

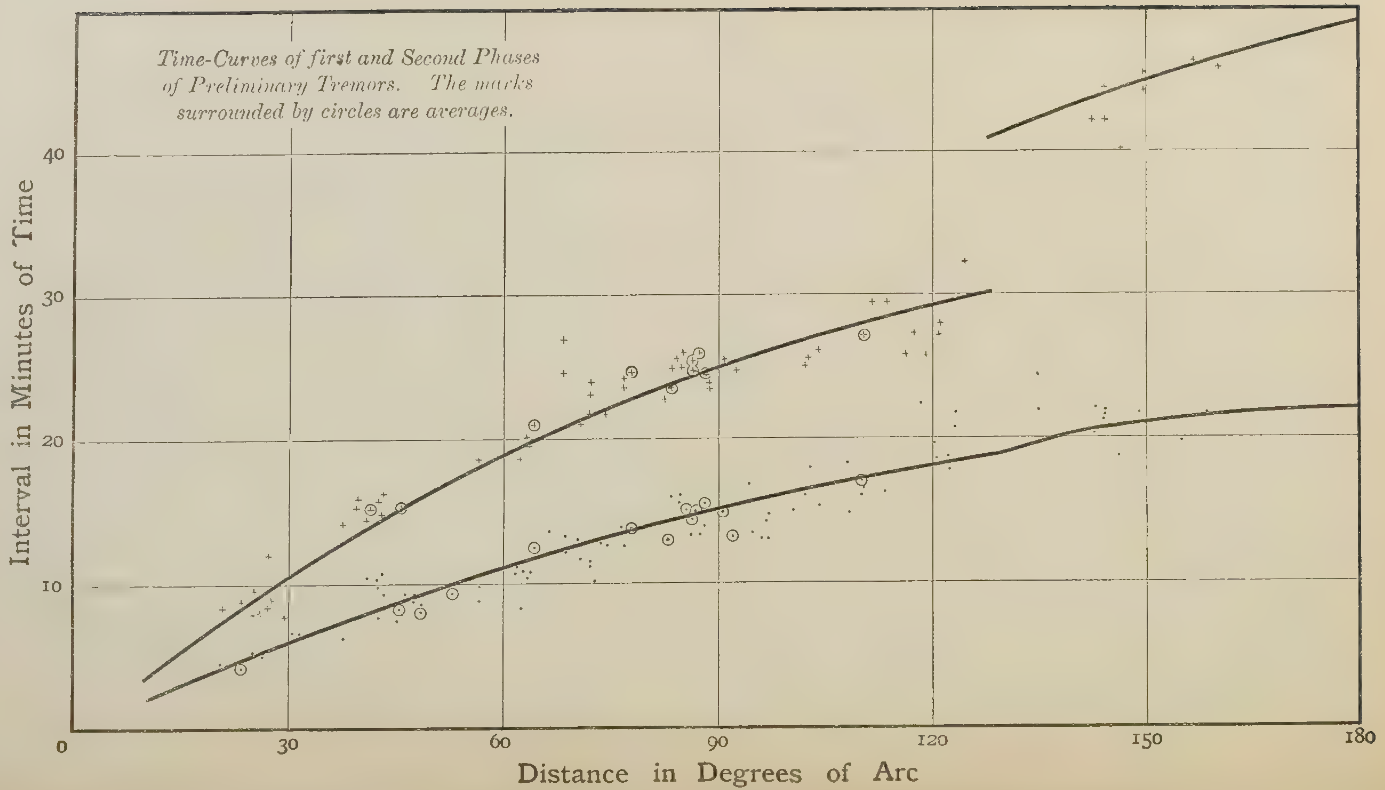
Such are the materials available. As may be noticed, there are discrepancies, and the time-intervals do not increase regularly with

[1] In the first case, the time is a little uncertain, owing to failure of the occulting watch. See Brit. Assoc. Seismological Circular, No. 1, 1900.

[2] 'Kort Verslag over de Aard- en Zeebeving op Ceram den 30 Sept. 1899' Natuurkundig Tijdschrift voor Nederlandsch-Indië, vol. lx (1900) pp. 219–28.

[3] Beiträge zur Geophysik, vol. vi (1904) pp. 238–66.

Fig. 1.


Time-Curves of first and Second Phases of Preliminary Tremors. The marks surrounded by circles are averages.
Interval in Minutes of Time
40
30
20
10
0
30
60
90
120
150
180
Distance in Degrees of Arc

the distance: the discrepancies being due, as has been explained, partly to inaccuracies in the distant records, and partly to errors in determining the time of origin. Another possible source of discrepancy is the possibility that the rate of propagation is not uniform in every direction, and that the time taken by wave-motion in travelling, say from Japan to Europe, is different from that taken by the same form of wave-motion in travelling from an equal distance in America. There are some indications that such is the case; but the difference is small, in comparison with the whole interval, and as the point is not material to the present investigation, it may be ignored, and the irregularities smoothed to a regular time-curve.

This is best done graphically, as is represented in fig. 1 (p. 462), where the averages of groups, and the single observations not adapted to averaging, have been plotted, and average time-curves drawn for the first and second phases.

It will be seen that the time-curves of the first two phases are very similar in shape, up to 120° from the origin; but beyond this they differ radically in form. That of the first phase, after an irregularity between 130° and 140°, becomes very flat and proceeds almost horizontally from 150° to 180°; that of the second phase comes to an end at 130° from the origin, and is continued some 11 minutes farther up. It is the explanation of these irregularities with which this paper is mainly concerned; and, to simplify the consideration of this problem, I have found it convenient to tabulate the figures represented by the time-curves, as they are more concordant and useful than the individual records. This has been done in the appended table (p. 464), which gives the intervals of time, to the nearest even minute, at each 30° of arc from the origin to its antipodes, the value for the last-named being inferred and not the result of direct observation.

In addition to the intervals of time, the mean apparent rate of propagation along the arc and the chord is given, regarding which a few words of explanation are requisite. The difference between the true and the apparent rate of propagation of an earthquake has long been familiar to seismologists. The first is the rate as measured along the direction in which the wave-motion is propagated, the latter is the resulting apparent rate of propagation, measured in some other direction, usually along the surface of the earth. Neither of these is readily determinable at any point, except by the construction of the time-curves, such as are drawn in fig. 1 (p. 462); but if the time be known at two points, then the difference in distance from the origin, divided by the difference in time, gives the mean apparent rate of propagation as between those points. In the table (p. 464) one point is supposed to be the origin, and two values of the mean apparent rate of propagation in kilometres per second are given, according as the distance is reckoned along the surface of the earth or in a straight line through it. It is not suggested that the wave-paths lie along either of these lines, but the values calculated are the material from which the true form of the wave-paths can be determined.

Table showing the Time taken by Waves of the Two Phases of Preliminary Tremors in travelling from the Origin, and Mean Apparent Rates of Transmission along Arc and Chord; together with Distances, and Maximum Depth of Chord from Surface, calculated for a Spherical Globe of 40,000 kilometres circumference, and for Intervals of 30° of arc.

Distance.	First Phase.			Second Phase.			Length		Maximum depth of Chord.
	Interval.	Rate along *Arc.*	Rate along *Chord.*	Interval.	Rate along *Arc.*	Rate along *Chord.*	*of Arc.*	*of Chord.*	
Degrees.	Minutes.	Km. sec.	Km. sec.	Min.	Km. sec.	Km. sec.	Km.	Km.	Radius.
30 ……	6	9·26	9·15	11	5·05	4·99	3,333·3	3,295·5	·034
60 ……	11	10·10	9·65	19	5·85	5·58	6,666·6	6,365·5	·134
90 ……	15	11·11	10·00	25	6·66	6·00	10,000·0	9,003·5	·293
120 ……	18	12·35	10·21	29	7·66	6·34	13,333·3	11,027·5	·500
150 ……	21	13·23	9·76	45	6·17	4·55	16,666·6	12,297·0	·741
180 ……	22	15·15	9·65	50	6·67	4·24	20,000·0	12,733·0	1·000

It should be noted that the intervals and resulting rates must not be taken too literally: the result of averaging observations is, indubitably, to increase the interval and lessen the apparent rates; but, besides this, an allowance ought to be made for the reduced rate of propagation of the disturbance through the outer crust of the earth. The amount of these corrections is not accurately determinable, but as they are in the same direction in every case, and as both together would, probably, not amount to a minute of time, they may be neglected so far as the conclusions drawn below are concerned.

III. The Deductions.

Wave-motion originating at any point in the earth will be propagated in all directions from it, and whatever the nature of these waves their wave-paths will be straight lines so long as the velocity of propagation remains constant; but, if this varies, the course of the wave-paths will be altered according to the laws of refraction, which are to be found in every text-book of physics. These laws hold good whatever be the nature of the wave-motion, although, in the case of elastic waves, the rate of propagation is dependent on two factors—the elasticity and density of the medium through which they are propagated. From this it will be seen that any information that we can get regarding the form of the wave-paths will indicate the changes, if any, in the rate of propagation, and thence in the physical condition, of different parts of the earth traversed by the wave-paths which emerge at different parts of its surface.

It will not be necessary to enter into details as to the manner in which the wave-paths can be determined from observations of the time of arrival of the disturbance; for the subject has been fully dealt with as a mathematical problem by Dr. Rudzki [1] of Cracow, and it will only be necessary to apply his conclusions.

In the first place, if waves are propagated along the surface of the earth, or at a short distance below but parallel to it, the mean apparent rate of propagation, as measured along the surface of the earth, will be constant for all distances. This is the case, or nearly the case, for the third-phase waves, which are, consequently, accepted as surface-waves, and can, therefore, give no information regarding the central portions of the earth. In the first and second phases this is obviously not the case: in the first phase there is a continuous increase in the apparent rate of propagation, and although there is irregularity in the rates calculated for the second phase, these are higher for distances beyond 90° than for lesser distances. These facts lead to the conclusion that the first and second-phase waves cannot be surface-waves, nor waves propagated a short distance below the surface, but must be mass-waves propagated through the body of the earth.

In considering the form of the paths along which these waves are propagated, it will be convenient to consider each quadrant

[1] Beiträge zur Geophysik, vol. iii (1898) pp. 495–518.

separately, dealing first with the wave-paths which emerge at distances up to 90° from the origin, and then with those which emerge at distances beyond that.

If the rate of propagation through the earth were uniform in all directions and at all depths, the wave-paths would be straight lines, and the mean apparent rate of transmission, along the chord, would be the same for all distances. It is obvious that this is not so, for the apparent rate of propagation, as measured along the chord, increases continuously up to 90°, in the case of both first and second phase-waves. This means that the waves travel faster as they penetrate to greater depths, and consequently the wave-paths are not straight lines, but curves whose convexity is directed towards the centre. Besides this, the fact that the increase in apparent rate of propagation is proportionately greater in the case of the second phase, shows that the curvature of its wave-paths is greater than in the case of the first-phase waves.

It must, however, be noticed that, although the increase in apparent rate of propagation is greater in the one case than in the other, yet the rate of increase as between 30°, 60°, and 90° is practically the same in both cases. The actual figures are as follows:—

		First Phase.	*Second Phase.*
Increase of apparent velocity along the chord	30° to 60°	·055	·118
Ditto	60° to 90°	·036	·075
Ratio of increments............	......	·65	·64

These figures show that the apparent rate of propagation increases with the distance about twice as rapidly in the case of the second as in that of the first-phase waves; that the rate of increase is not uniform, but diminishing with increasing distance; and that in both cases this alteration is in the same direction and at the same rate. This suggests that the increase in rate of propagation with increase in depth of the wave-paths is not due to their passage through material of a different character, but may be merely the effect of increased pressure and temperature, and consequently, that the substance of which the earth is composed—below the outer crust—undergoes no material change in composition or physical condition, at least to the depths reached by the wave-paths of earthquake-waves emerging at 90° from the origin.

This much is independent of any assumption regarding the nature of the wave-motion, but without making some assumption regarding this, no further information is attainable. I shall take it that the first-phase waves are condensational—this being generally acknowledged—and that the second-phase waves are distortional, an assumption which I regard as more than probable, and on these assumptions it is possible to estimate the proportion which the modulus of rigidity bears to the bulk-modulus, or resistance to compression. In making this estimate we may take the wave-paths for the two waves as being so nearly coincident that there is no material difference in the density of the medium. The calculation being simple, it is only necessary to state the results, which are

that on wave-paths emerging at 30° from the origin the rigidity is ·385 of the bulk-modulus, for paths emerging at 60° it is ·446, and for those emerging at 90° it is ·493; that is to say, the rigidity or power of resisting distortion increases at a greater rate than the solidity, or power of resisting compression.

If absolute values of these two moduli are required, it is necessary to make some assumption regarding the density of the medium through which the waves are transmitted, and if it be assumed that Laplace's law of densities is correct and that the mean density[1] of the medium traversed is about the same as that at the greatest depth reached by the chord, we get the following values for the mean rigidity and bulk-modulus, both being measured in C.G.S. units:—

Arc.	Assumed density.	Modulus of Resistance to Compression.	Modulus of Resistance to Distortion.
30°	3·00	$151{\cdot}6 \times 10^{10}$	$74{\cdot}7 \times 10^{10}$
60°	4·25	$219{\cdot}4 \times 10^{10}$	$132{\cdot}3 \times 10^{10}$
90°	6·20	$322{\cdot}4 \times 10^{10}$	$223{\cdot}2 \times 10^{10}$

These figures should be regarded as arithmetical curiosities rather than actual measures, for, apart from uncertainty regarding the density of the medium, the mean apparent rate of propagation, as measured along the chord, is certainly less than the true mean rate, as measured along the actual wave-path, and the maximum rate is greater than this again; yet, despite this, the figures indicate that the material traversed by the waves is endowed with a very high degree of rigidity and resistance to compression. In the case of the waves emerging at 90° from the origin, the material traversed has, on the average, nearly 12 times the resistance of granite to compression and 15 times its rigidity; if the density remains constant, these figures would be reduced by about three-tenths, but on the other hand the maximum values will be higher.

It must, however, be borne in mind that this high degree of rigidity, as against stresses of very short duration, is quite compatible with the yielding to stresses of long duration, which is required by known facts of structural geology, and need not necessarily be inconsistent with those movements, of the nature of convection-currents, which Mr. Fisher[2] believes to exist in the interior of the earth.

Turning now to the second quadrant, it will be convenient to take each phase separately, and to commence with the second phase.

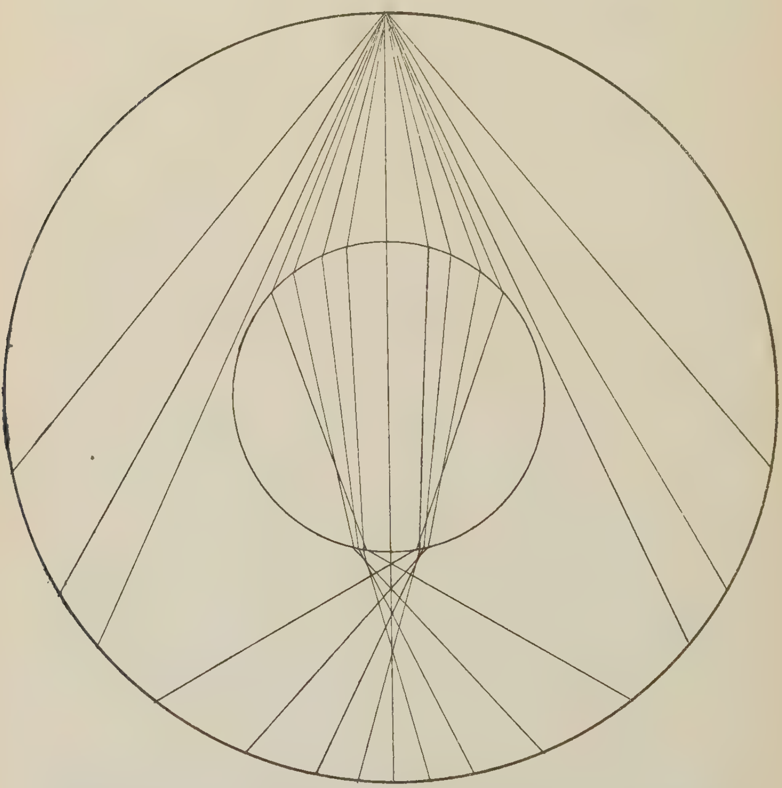
The table (p. 464) shows that at 120° the increase in the mean apparent rate of propagation is more than maintained, but too much importance must not be attached to the exact figures, for the interval at 120° is somewhat uncertain. Most of the records from about this distance are late commencements, attributed to the second

[1] Strictly speaking, the square root of the mean of the squares of densities.
[2] 'Physics of the Earth's Crust' 2nd ed. (1889) chapters vi & xxiii.

phase; and, if these be excluded, the interval will be a little longer, and the apparent rate of propagation a little less, than is indicated in the table.

At 150° from the origin we find a remarkable decrease in the mean apparent rate of propagation, which drops from an average of over 6 to about $4\frac{1}{2}$ kilometres per second, and the most obvious explanation of the decrease is that these waves, penetrating to greater depths, have entered, and for part of their

Fig. 2.

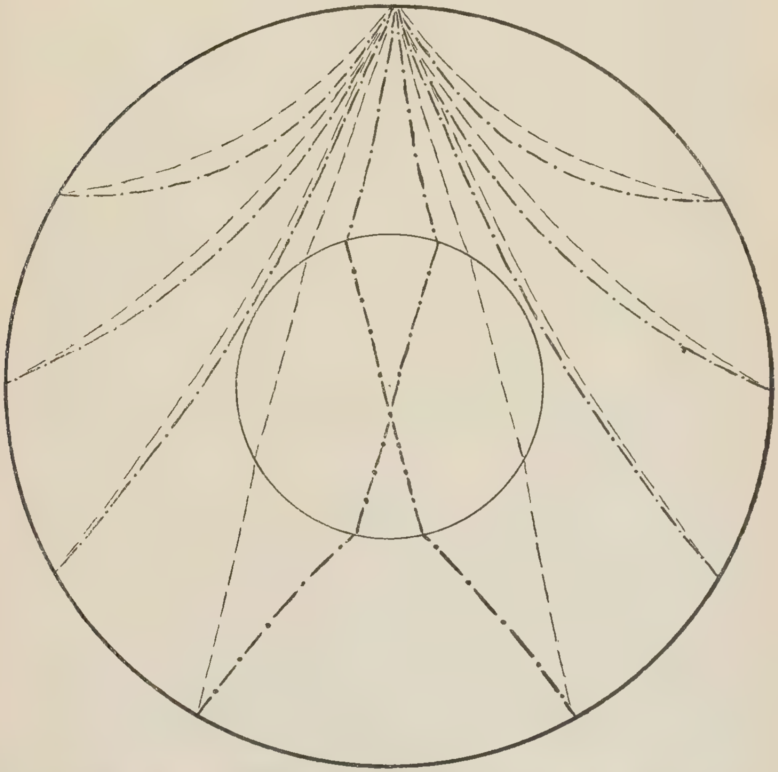


way traversed, a central core, composed of matter which transmits them at a much slower speed than that traversed by the waves emerging at lesser distances from the origin. The only other alternative is that the time-interval is wrong, and that we are not dealing with the second-phase waves at all.

As regards this hypothesis, I may point out that all the determinations used at distances of over 120° are derived from my own examination of the original records or copies from them. In every

case the second phase, as adopted, presents the same characters as those which I had recognized at lesser distances; and if the times given do not refer to the second phase (in the sense used elsewhere by me), then this phase is not represented at all in the more distant records, and instead of a central core which transmits the waves more slowly, there must be one which is incapable of transmitting them at all, thus leading to the same conclusion, that

Fig. 3.



[The broken lines represent the first phase, the broken-and-dotted lines the second phase, and the continuous curve the third phase.]

the deeply penetrating wave-paths enter matter of very different constitution from that traversed by the shallower paths.

Rejecting the supposition that the second-phase waves are extinguished by the central core, and accepting the more probable one that the rate of transmission is reduced in it, there remain two

important questions to be answered, namely, the size of the core and the rate of transmission of the waves in it.

As regards the size of the core, we have seen that it is not penetrated by the wave-paths which emerge at 120°; and the great decrease at 150° shows that the wave-paths emerging at this distance have penetrated deeply into it. Now, the chord of 120° reaches a maximum depth from the surface of half the radius, and we have seen that the wave-paths up to this distance are convex towards the centre of the earth, so it may be taken that the central core does not extend beyond about ·4 of the radius from the centre.

As regards the rate of transmission of the waves, the data hardly deserve elaborate mathematical treatment until more have been collected, but it is easy to arrive at an approximate estimate of the rate of transmission and the nature of the wave-paths. The chord of 150° has a length of 12,297 kilometres, of which 8413 km. lies in the outer ·6 of the radius and, at a mean rate of 6 km. sec., requires 23·4 minutes, leaving 21·6 minutes for the remaining 3884 km., or a mean rate of 3 kilometres per second.

This reduction in speed has an important and unexpected result, for it means a refractive index of 2·0 and a great deviation of the wave-paths as they enter the central core. As a first approximation to the actual course of the wave-paths, I give, in fig. 2 (p. 468), a representation of what they would be on the supposition of a central core, occupying ·4 of the radius, in which the rate of propagation is one half of that in the outer shell; in this it will be seen that the wave-paths emerging at 150° reach their emergence after passing on the opposite side of the centre of the earth, and exhibit that concavity towards the centre which Dr. Rudzki's investigation requires where increase in depth of wave-path is accompanied by a decrease in the rate of propagation.[1] The actual wave-paths, however, are not, as has been shown, composed of straight lines, and the real wave-paths must be more like what is indicated in fig. 3 (p. 469), which may be taken as correct in kind, though perhaps wrong in detail, as to the actual position of the wave-paths.

The high index of refraction prevents the formation of a complete shadow-band, for the most extreme of the rays which enter the central core suffer so great a deviation that their point of emergence at the surface overlaps that of the last rays which miss the central core; but an inspection of figs. 2 & 3 will show that there should

[1] The wave-paths shown in fig. 2 give, for an emergence at 150° and at a time-interval of 45 minutes, a rate of transmission of 3·5 km. sec. in the central core, and 7·0 km. sec. in the outer shell. These values are higher than can be admitted; the explanation probably lies in the shortening of these long-distance wave-paths which results from their curvature, as shown in fig. 3, and possibly also in a lesser ratio than that of 2 : 1 of the rates of transmission, or a lesser size of the central core. It may also be noticed that rates of 7·0 and 3·5 km. sec. respectively give an interval for the diameter of about 42·5 minutes; and although this value cannot be accepted, it indicates a possibility that the emergence of the second-phase waves at the antipodes of the origin may actually be earlier than at a distance of 150°.

be a zone, at about 140° from the origin, where the second-phase waves would be so dispersed, and consequently feeble, that it would practically amount to a shadow, and the second phase should be absent in records from this distance, or much more feebly marked than in those from greater or lesser distances.

The effect will be modified by the fact that the transition from central core to outer shell is not abrupt but gradual, though comparatively rapid; yet it is worth noting that, so far as the limited amount of available material may be trusted, the second phase is certainly much less marked at about 140° from the origin than at distances of less than 130° or more than 150°. For instance, the Guatemala earthquake was recorded at Bombay, 144° from the origin, by three instruments. On one record no indication of a second phase can be found; on another it is so indistinctly marked that it can hardly be recognized as such; and even on the Milne pendulum, which shows what I take to be the second phase most distinctly, it is not at all characteristic. The Batavian record of this same earthquake, at a distance of 160° from the origin, shows it much more distinctly: and on the Cape-Town records of the Alaskan earthquakes at 150° from the origin it is easily recognizable.

These considerations lead to the conclusion that the time-curve of the second-phase waves is not a continuous line. Up to about 130° it is continuous, and represents the emergence of waves which have travelled directly from the origin; beyond that distance it represents waves which have been refracted, after passing on the opposite side of the centre of the earth, and it would be misleading to join the two into one continuous curve. For these reasons, the second-phase time-curve has been drawn as it is shown in fig. 1 (p. 462).

We may now turn to the first-phase waves, and see how they are affected by the central core. At 120° the increase in mean apparent rate of transmission is maintained, but at 150° the rate has dropped to 9·76 km. sec., and the value is a good one. There can be no doubt that the drop is real, but it is much less than in the case of the second-phase waves, and merely represents a diminution of the rate of propagation by about one-tenth.

From this it will be seen that the central core behaves differently from the outer shell with regard to the first, as with regard to the second phase, but the change is much less in amount, and would probably have remained undetected were it not for the very conspicuous alteration in the case of the second-phase waves.

IV. Conclusions.

From the considerations detailed in the foregoing pages, I conclude that the interior of the earth, after the outermost crust of heterogeneous rock is passed, consists of a uniform material, capable of transmitting wave-motion of two different types at different rates of

propagation: that this material undergoes no material change in physical character to a depth of about six-tenths of the radius, such change as takes place being gradual and probably accounted for sufficiently by the increase of pressure; and that the central four-tenths of the radius are occupied by matter possessing radically-different physical properties, inasmuch as the rate of propagation of the first phase is but slightly reduced, while the second-phase waves are either not transmitted at all, or, more probably, transmitted at about half the rate which prevails in the outer shell.

If these waves are to be explained as those of condensation and distortion, then the ratio between the modulus of rigidity and the bulk-modulus is only two-thirds of that obtaining in the outer shell; but whether this interpretation be adopted, or that of Mr. Fisher, or some other yet unproposed, we still have a central core the behaviour of which with regard to these waves differs materially from that of the outer shell. I do not propose to enter into speculative grounds, or to offer any opinion as to whether this central core is composed of iron, surrounded by a stony shell, or whether it is the central gaseous nucleus of others. On this occasion, it is enough to have shown that there is a difference which cannot be overlooked, and must be taken into account in any hypothesis that may be formed regarding the constitution of the interior of the earth.

Table I.

Group-Average Intervals for Propagation of First- and Second-Phase Waves from their Origin to the Place of Observation.

Distance: Degrees.	*First Phase.*		*Second Phase.*		*Earthquake. Ser. No.*
	Observ. No.	*Interval: Minutes.*	*Observ. No.*	*Interval: Minutes.*	
23·4	6	4·2	...	...	12
41·7	...	...	8	15·0	7
45·9	17	8·2	7	15·1	12
48·5	5	8·0	...	...	"
53·1	5	9·1	...	...	"
64·2	13	12·4	11	20·7	5
78·0	7	13·5	5	24·4	11
83·3	33	12·8	30	23·5	9
85·2	5	14·8	...	...	1
86·3	5	14·1	8	24·6	4
86·8	7	14·5	10	25·2	8
87·9	...	...	6	25·7	3
88·1	9	15·1	7	24·4	6
90·8	20	14·8	14	25·1	11
92·3	11	13·1	8	24·6	10
145·6	5	21·7	...	...	11

Table II.

Average for all Earthquakes, grouped for intervals of 5° of arc.

Distance: Degrees.	First Phase.		Second Phase.	
	Observ. No.	Interval: Minutes.	Observ. No.	Interval: Minutes.
45	14	8·3	8	15·0
50	8	8·4	...	...
55	7	9·2	...	...
65	13	11·8	11	19·8
70	9	11·9	9	22·9
75	8	13·1	8	23·6
80	13	12·7	10	23·8
85	42	13·6	47	24·1
90	36	15·0	37	24·9
95	14	13·9	12	25·3

Table III.

Intervals from Origin to Commencement of First and Second Phases, as recorded at Distances of over 100° from the Origin.

Distance.	Earthquake No. and Place of Record.	First Phase.	Second Phase.
100·3	11 Nikolaiew	15·0	...
102·5	11 Wellington (N.Z.)	16·0	25·0
102·8	2 Rome..........................	17·8	25·2
104·5	11 Christchurch (N.Z.).........	15·2	26·0
108·5	10 San Fernando	14·7	...
108·5	10 Cape Town	18·1	27·6
110·7	11 Tiflis	16·2	...
,,	,, ,, ...	16·2	...
,,	,, ,, ...	16·3	...
111·9	11 Irkutsk	...	29·5
113·9	11 Cape Town	16·4	29·6
117·6	2 Nikolaiew	...	27·1
118·4	10 Toronto........................	(22·6)	...
120·2	12 Christchurch (N.Z.).........	19·6	(40·2)
120·9	2 Kharkow	18·6	...
121·3	11 Tashkent	17·9	27·2
,,	,, ,, ...	18·5	28·1
123·3	10 Baltimore	21·7	...
124·8	9 Trinidad	...	32·5
134·9	9 Cape Town	22·0	...
,,	,, ,, ...	24·1	...
142·9	11 Calcutta	22·0	...
144·1	11 Bombay........................	21·3	(42·5)
,,	,, ,, ...	21·8	(44·8)
,,	,, ,, ...	21·4	...
146·8	12 Cordoba (Arg.)	18·5	40·2
149·8	11 Perth (W.A.)	21·8	(40·0)
154·4	10 Trinidad	21·5	...
157·4	9 Cordoba (Arg.)..............	19·8	(39·5)
,,	,, ,, ...	23·6	46·5
160·4	11 Batavia	21·7	46·0

Discussion.

The President referred to recent physical speculations as to the condition of the earth's interior, and particularly to those of Arrhenius. There could be little doubt that we were on the eve of important additions to the data hitherto available for discussing this subject. The establishment of accurate self-registering instruments all over the world for recording earthquake-movements had provided a new method of investigation, as the Author had shown by his previous papers and by the interesting communication that he had now made to the Society. In his diagrams, the Author had represented the path of the wave as abruptly refracted against the inner nucleus of the globe; but he would no doubt admit that there must be a gradual transition from the material of the nucleus into that of the external portions. The President was glad to hear the Author's generous recognition of the value of the work accomplished by Prof. John Milne, who must be regarded as the great pioneer of modern seismology. Prof. Milne had been recently invited by the Royal Society to give the Bakerian Lecture next month, on recent advances in seismology, a lecture to which physicists and geologists were looking forward with much interest.

Dr. J. W. Evans enquired as to the nature of the difference between the waves of the first and second phases recorded by seismographs.

Mr. A. P. Young wished to ask whether he was right in supposing that the Author's hypothesis required a division of the earth's sphere into two portions—a highly-refringent core, separated by a distinct boundary from a rind of greater elasticity. If that were the case, the speaker thought that he saw the necessity for some postulate as to the conditions of elasticity in the outer shell, on the basis of which the curve of the rays, and ultimately the diameter of the core, might be estimated.

Mr. G. W. Young understood that, if one type of seismograph were used, the waves of the third phase were much larger than those of the second phase, while with another type of instrument the reverse was the case; so, apparently, the relative sizes of the waves depended upon the instrument used. Did not that make it difficult to determine which of the two phases was really the more powerful?

The Author, in reply, said that he believed that the passage from the outer shell to the central core was probably gradual, but certainly rapid. The supposition of an abrupt change was convenient, as the passage seemed to be so rapid that it would only be represented by a line on the scale used in the diagram; whether gradual or abrupt, there would be no difference in the ultimate amount of refraction. The difference in character of the seismograms depended on the fact that pendula of short period were usually fitted with arrangements for a large multiplication of the actual displacements. The record of the first and second phases being mainly due to inertia, and the actual displacement being approximately the same in each case, the resulting record was naturally larger in the case of

those instruments giving the greater amount of amplification of the record. In the third phase, the record was principally due to tilting, added to the natural swing of the pendulum, and the displacement due to these causes being much greater in the case of horizontal pendula of comparatively-long period, the record was naturally larger, despite the lesser degree of magnification. In practice there was usually no difficulty in allowing for the differing behaviour of different types of instrument, and in recognizing the phases of the disturbance despite their great apparent contrasts in appearance. As regarded the interpretation of the record and the types of wave-motion, he believed that the one adopted by him was most in accordance with all the facts; but he was ready to adopt the Rev. O. Fisher's alternative explanation of the second-phase waves. So far as the conclusions drawn in his paper went, the only essential point was that both these phases are due to mass-waves of two distinct kinds, both propagated through the earth, and not along or parallel to its surface.

20. *The* Eruption *of* Vesuvius *in* April 1906. By Prof. Giuseppe de Lorenzo, For.Corr.G.S.[1] (Read May 9th, 1906.)

After the great eruption of April 26th, 1872, the exhausted volcano lapsed into comparative repose for three years, a repose marked by merely solfataric phenomena, to awaken again in 1875, however, to a state of strombolian activity, which continued until the beginning of this present month of April, punctuated now and then by phases of lateral outpourings of lava, such as those of the years 1885, 1889, 1891, 1895, etc. In the course of these the great cone was fissured, and there flowed from the fissures month after month and year after year, piling up on itself, a lava mostly of the Pahoehoe type, dense and pasty, that is, insufficiently saturated with steam and superheated water.

Meanwhile, however, the quantity of this water was slowly increasing within the subterranean furnace, as was proved by the great outbursts from the principal crater, which took place in May 1900 and September 1904. As the amount of this steam and the degree of its tension continued to increase, on May 27th, 1905, fissures were rent in the north-north-western wall of the cone, whence rivulets of lava began to pour forth, from an altitude of about 3600 feet. This went on until the beginning of the present month of April, the new lava finding its way down the little valley which runs between the two hills of lava heaped up by the eruptions of 1891 and 1895, and flowing also westward in such wise as to cut the electric railway along that portion of the track which lies between the Observatory and the cable-railway.

And now, on the morning of April 4th, the great cone, probably unable to withstand any longer the increased tension of a magma already saturated with steam, was cleft on its south-south-eastern flank by long fissures, corresponding as to their axial planes with the fissures torn in previous years in the opposite flank. On the 5th, from the base of one of these freshly-opened fissures, near the Casa Fiorenza, at an altitude of some 2460 feet above sea-level, a small stream of lava poured forth, while from the principal crater a great jet of steam burst with explosive force, laden with scoriæ and lapilli caught up from the new cone. Then ensued a pause in the flow of lava, during which interval the steam, now freed from an excess of pressure, made ready for a fresh effort.

And so, between the 6th and 7th of April, while the great threatening pillar of black and brown lapilli was looming ever more colossal towards the heavens, occupying well nigh one half of the northern horizon, deeper and longer fissures than before yawned in the south-eastern wall of the cone. From the orifice previously mentioned, from another which opened up below the Valle dell' Inferno, and more particularly from a third, near the so-called

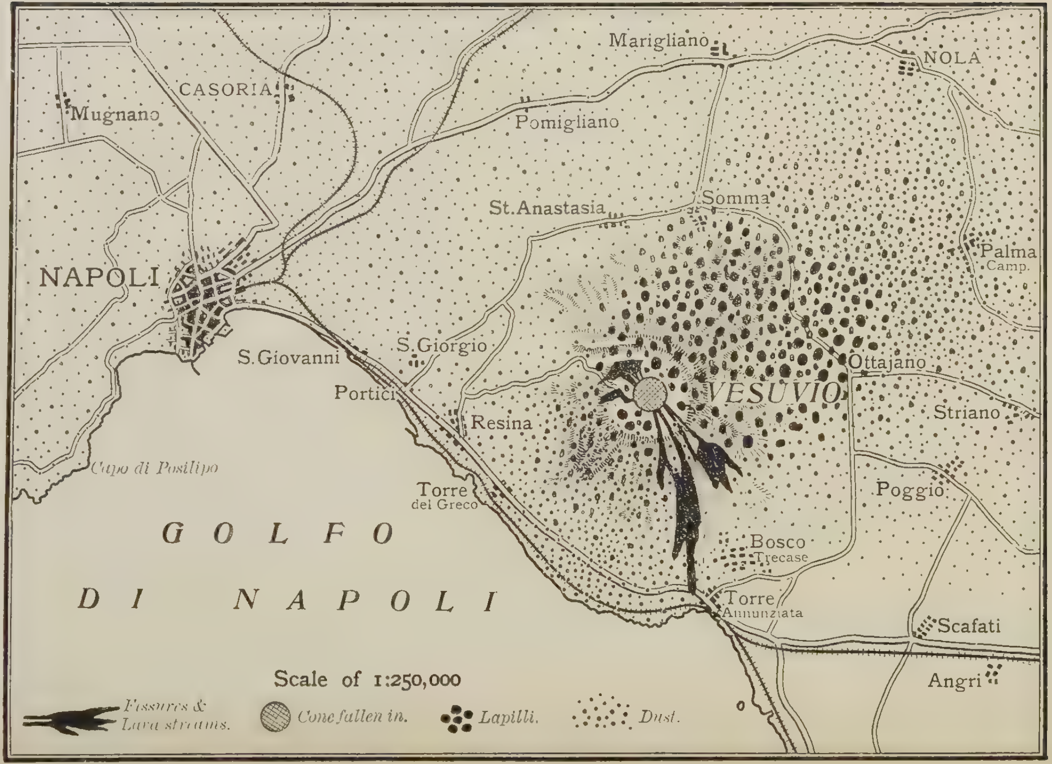
[1] Translated from the Italian by the Assistant-Secretary.

Cognoli (at an altitude of about 2000 feet), issued a great mass of fluid lava, scoriaceous, and laden with steam, like unto that of 1872. In a very short time this stream advanced close to the cemetery of Boscotrecase, devastating remorselessly on its way farm-houses and vineyards.

Then ensued another pause, in some sort preparatory to the maximum outburst, which took place during the night of the 7th to the 8th of April. During the evening of the 7th there were formidable explosions from the principal crater, spurting 3000 feet up into the sky fragments of incandescent material; and these explosions reached a climax between midnight and dawn of the 8th, causing the earth to quake as far as Naples itself, and belching forth an enormous quantity of scoriæ and lapilli derived from the magma, as well as masses of the crateric cone, which was by this time in course of demolition. These ejectamenta, impelled by a strong south-westerly wind, destroyed the villages of Ottajano and San Giuseppe, burying them beneath a layer of lapilli more than 2 feet thick, and killing some 200 of the hapless inhabitants. Moreover, the cloud of ashes descended threateningly on Nola, crossed the Apennines, and swept over the Adriatic into Montenegro. Concurrently with this outburst, the cone was cleft more deeply than ever before towards the south-south-east, while a fresh stream of scoriaceous lava rushed tumultuously forth, overwhelming that of the preceding day, cutting off the village of Boscotrecase in two portions of it which are called the Oratorio, and reaching within a few hours the cemetery of Torre Annunziata, against the walls of which it stopped, breaking into two branches.

With this outburst the maximum tension of the steam-saturated magma relieved itself, the climax of paroxysmal eruptivity was overpassed, and in the course of the 8th of April the decrescent phase began, though still alarming and dangerous. In fact, owing to the tremendous shock of the explosions, and the withdrawal of support by the outflow of lava from its flanks, the cone of the principal crater collapsed, having been cleft to a depth exceeding 300 feet. Thereby it choked up the throat of the volcano, and opposed a fresh hindrance to the ejection of the steam still present at some depth below. In the evening of the 8th this steam burst forth continuously in huge jets from the crater, but without otherwise causing any considerable commotion, carrying with it the comminuted fragments of the cone in the shape of immense rolling clouds of dust which soared majestically into the sky up to heights of 21,000 or 22,000 feet or more. These formed a great leaden 'pine,' enveloping the ordinary clouds of the atmosphere, across which zigzagged every now and then flashes of lightning accompanied by a tremendous roar of thunder. This imposing spectacle was magnificently seen from Pompei, as the wind, still blowing from the south and south-west, impelled the gigantic cloud of dust to move northward and north-eastward; it descended with fatal effect on the Campania Felice, accompanied by showers of mud-laden rain and emanations of sulphur-dioxide (SO_2), mantling the countryside with

Fig. 1.—*Map illustrating the general results of the eruption of Vesuvius in April, 1906.*



a grey shroud, which even at a distance of over 9 miles from the crater approaches an inch in thickness.

On the morning of the 9th the wind veered round to the north-east, blowing the dense column of dust, which interposed like a great veil between Naples and Sorrento (fig. 2, p. 480), first towards Ischia and then towards Capri, causing it to drift south-westward until it deposited the material with which it was laden far into Spain. This wind lasted over the whole of the 10th of April as well—with grave results to Torre del Greco, which, lying directly in the track of the dust-cloud, was enveloped in pitch-darkness for two days, buried under a layer of dust a foot thick, and would have assuredly suffered the same fate as Ottajano, had not the wind again veered in the night of the 10th to the 11th, impelling northward the death-dealing cloud. Blown hither and thither, now by the sea-breeze, now by the land-breeze, this cloud hovered over the environs of Naples during the 11th and 12th, until on the day on which I am writing (the 13th) it seems finally to have bent its course to the northward.

Although several violent outbursts have taken place at intervals, there is no doubt that the height of the cloud-column (or 'pine') and the quantity of dust have on the whole diminished continuously from the 9th until this day (the 13th), and probably they will go on decreasing until all but complete exhaustion of the steam. The very character of the dust is no longer the same. That of the 5th of April consisted of dark blunt-edged granules, derived directly from the (as yet unaltered) new cone; while that of the 6th, 7th, and 8th became increasingly mixed with fragmental material of a lighter colour; the dust of the evening of the 8th and the following days, of a grey or pinkish colour, was entirely made up of débris of the broken-down old cone, which had already been subjected to the influence of fumarolic and atmospheric agencies.

The great cone, owing to the collapse of its upper portion, now presents, as seen from Naples, an almost horizontal rim, very little higher than the summit of Monte Somma, with a crater which may exceed 1500 feet in diameter. The base of the cone has been considerably broadened by the great mass of fragmentary material which has been projected from it. Moreover, the cone itself now looks white, as if covered with snow, owing to the pale coloration of the ash and the sublimates of ammonium-chloride and sodium-chloride with which it is encrusted, with perhaps, in places, chlorides of iron.

The effect on vegetation of that suffocating pall of dust cannot but be baneful. There where the lapilli and scoriæ fell thickest, dead birds are seen to bestrew the ground, with wide-open beaks, as if asphyxiated. Asphyxia, then, was one form of peril, but the greatest havoc was wrought by the very weight of the ejectamenta which crushed in the buildings, as was the case at Pompei. The lava-flows, on the other hand, although they permanently bury the ground out of sight, leave time to man and beast to seek safety in flight. The smaller plants take fire at the touch of the lava; but the bigger trees, whether struck down or left erect, do not catch fire,

Fig. 2.—*Dust-clouds seen at noonday, April 10th, from Santa Lucia.*

and their unsinged leaves and blossoms form a gay canopy over the stream of smoking lava, which surrounds them up to a height of 7 or even 10 feet, and flows onward. It may be that around such trees a scoriaceous crust forming instantaneously on the lava prevents immediate combustion, and they merely wither away slowly from desiccation.

[During the 7th and 8th of April the sea-level was lowered all along the neighbouring coast, by as much as 12 inches near Portici, and as little as 6 near Pozzuoli, and has not so far (April 13th) returned to its previous level. This would imply that there has been a real elevation in this part of the earth.]

It remains to mention that the lava, lapilli, and dust of this eruption are of the usual leucotephritic character observed in all the eruptions of Vesuvius, from 1872 until the present day.

The eruption of which a brief account has been given took place in clear and calm weather, while the barometer was high, and the sea was quite exceptionally smooth. The maximum of eruptivity coincided almost exactly with the full moon. The volcanoes of the Phlegræan Fields and of the Islands remained in their normal condition, which goes to prove that the shocks recorded in March at Ustica, and the Calabrian earthquakes of last September, had no connexion whatever with the phenomena here described.

Next to the great eruptions of 79 A.D. and 1631, I believe that the recent eruption is one of the greatest that history records from Vesuvius.

Postscript.

[Up to May 1905 the principal cone of Vesuvius had reached an altitude of 4,362 feet above the sea, being thus 650 feet higher than the crest of Monte Somma (3,712 feet above sea-level). In consequence of the eruption of April 4th/8th, 1906, and especially after the great explosions and fissurings which took place during the night of the 7th to the 8th, the cone of Vesuvius has changed completely in shape, being obliquely truncated by a new crateric rim, which on the south-west attains an altitude of 4,133 feet, and on the north-east an altitude of 3,673 feet above sea-level. This obliquity of the crater and of the explosions, directed north-eastward, as if proceeding from a siege-mortar trained in that direction, contributed far more than the prevailing wind to the destruction of Ottajano by masses of lapilli and scoriæ. The crater thus formed opens upward like a cup with oblique sides, and then plunges downward like a chimney with vertical walls, of which the depth cannot be ascertained beyond 650 feet down. The external crateric rim reaches perhaps a diameter of 1640 feet, and the throat of the internal chimney can hardly measure less than 1000 feet in diameter.

The great explosions hurled into the air (together with the pulverized magma, and the material of the fissured cone crumbled into dust) blocks and fragments torn out of the cone, which had

Fig. 3.—*Dust-clouds seen on April 10th, from nearly the same point of view as fig. 2.*

(From a photograph lent by Mr. Arthur Collins.)

previously undergone the action of fumaroles, in such wise as to originate the formation of minerals of metamorphic nature. Consequently, not only do chlorides and sulphates abound, but also ejectamenta of big crystals of magnesian mica, hornblende, pyroxene, etc., sometimes occurring singly, and sometimes grouped together in crystalline blocks such as those described by A. Scacchi from the eruption of 1872, and among which the presence of sylvite is noteworthy.—*May 30th, 1906.*]

Discussion.

The Chairman (Mr. A. Strahan) remarked that it had been a pleasure to hear this interesting account of the recent eruption from one of the Foreign Correspondents of the Society. The British Isles had been not inaptly described as a Museum of Geology, but they could show no active volcano.

Mr. W. V. Ball desired to know whether the extraordinary phenomenon of the sinking of the sea-level after an eruption was a frequent consequence of volcanic eruptions. He did not remember hearing of any such occurrence before; but there was doubtless some eminent geologist present who could enlighten him on that point.

Prof. Garwood said that he would like to call attention to the photograph and samples of dust exhibited through the kindness of Mr. Arthur Collins, who was present at Naples during the eruption. The dust illustrated in an interesting manner the variation in character which it underwent as the eruption progressed, owing to the changes which took place after the collapse of the cone, as described by the Author in his paper.

21. *The* Chalk *and* Drift *in* Möen. By the Rev. Edwin Hill, M.A., F.G.S. (Read March 21st, 1906.)

The volume for 1899 of the Quarterly Journal of the Geological Society contained a paper by Prof. Bonney and myself on the 'Relations of the Chalk & Drift in Möen and Rügen,' [1] in which we expressed the opinion that the existing dislocations of the Chalk had been produced before the advent of the Drift.

In 1904, there appeared a second edition of 'Danmarks Geologi,' by Prof. N. V. Ussing.[2] This, on p. 89, mentions the phenomena of Möen, and some of the explanations of them put forward. Forchhammer, it says, assumed that they were results of plutonic forces: Johnstrup considered them to be caused by the thrust of the mighty inland ice-sheet which passed over Denmark: German writers more recently have explained them as consequences of widespread earth-movements, with or without ice-thrust. But there is no allusion to the view taken in our paper; therefore I think that it may be useful to publish the results of further study made by me in 1903, 1904, and 1905.

The problem of Möen is to account for the position of some isolated small portions of clay, seen here and there included in the Chalk along a range of chalk-cliffs some 4 miles long. The beds are much dislocated. Forchhammer, followed by Puggaard and Lyell, regarded the disturbances as subsequent to the Glacial deposits, and the Drift-inclusions as portions engulfed. Johnstrup, regarding the disturbances as due to thrust of the ice-sheet, considered the Drift-inclusions as introduced by the same agent. Prof. Ussing remarks that the inclusion of Quaternary deposits between portions of Chalk proves the disturbances to be of Quaternary age. It is thus universally assumed that the inclusions occupy dislocations, and entered them while they were being produced. Prof. Ussing, while noticing the different theories, does not appear to adopt any of them, and points out objections to each: other difficulties are mentioned by Prof. Bonney and myself, in our paper. I am now able to bring forward evidence that the dislocations had been produced before the Drift entered them: that they are older than the Ice-Age, and accordingly are not the work of ice-thrust, nor yet of post-Glacial disturbances.

Storre Taler is a headland of Chalk over 300 feet high, from which a wall of chalk runs southward, banded with flint-lines which undulate, but on the whole lie horizontally. High up on the face of this wall can be seen three or four oval hollows lying at the same level. All their contours are rounded, at their bases are accumulations of flints, and they have every appearance of being water-worn cavities. They are filled with Drift: and so must have

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 305–24.
[2] Danmarks Geologiske Undersögelse, ser. 3, No. 2.

existed before the Drift came. Here, at any rate, the Drift-inclusions must have been introduced into pre-existing cavities. These cavities were not caused by ice-thrust or by post-Glacial earth-movements.

Dronningstolen is a long cliff, more than 400 feet high, of much-disturbed and fractured Chalk. Two fissures are conspicuous on the face. They start from a hollow on the cliff-edge and diverge right and left, running down through some half the height of the vertical chalk-wall. At two or three points they widen out into large cavities; but ultimately they die away in cracks. The shapes of the cavities are not such as would be expected from dislocation by ice-thrust or earth-movement. Examination showed that the roof of the largest one was undulating, arched, waterworn. Here, therefore, are fissures enlarged by percolation of water. But the hollow from which they start, the fissures themselves, and the cavities, are filled with Drift. These cavities must have existed before the Drift came: they are formed in fractures, consequently the fractures must be older than the Drift.

The cliff of Dronningstolen is ended on the north by a deep gully. Beyond this projects the headland called Forchhammers Pynt: the southern face of this is a vertical white wall, which drops into the gully about 200 feet above the sea, and the same distance below the summit. On this white face, at some height above the gully-bed, is a patch of stones, apparently plastered on to the face. The stones are large, some measuring a foot across. Examination shows that the end of the patch is overhung, and to some extent overarched, by the Chalk. So, here again, there seems to be a waterworn cavity. But the gully is filled with Drift, which extends continuously from the beach to the top of the cliff, and itself contains large stones. Thus the stone-patch and gully appear to be relics of a clay-filled fissure, and corroborate the conclusion that the disturbances are considerably older than the Drift. This is fatal to Johnstrup's theory that the thrust of the ice-sheet was their cause, and fatal to the general assumption of their Glacial or post-Glacial age.

Waterworn cavities must arise in a shattered mass of Chalk such as Möens Klint, for water percolating along lines of fracture must enlarge them into clefts and cavities. This process must still be going on. The singularly-irregular hill-surface has many dry basins.[1] The water which might gather in these, but does not, must find its way along subterranean channels. Some of it issues by the spring of Maglevand, the most copious along the cliffs. This breaks out about 100 feet below the cliff-edge, and pours quite a considerable stream down to the sea.

Besides the three cases of Drift-inclusions just described, many others occur, belonging to several types. There are notches filled with Drift, as one on the face of Hylledals Klint, which was

[1] Noticed by Puggaard.

figured in our former paper.[1] There are bands of Drift seeming to run a few yards horizontally, as a group of two (or three) on the cliff north of Maglevand, and one figured in a former paper.[2] There are gullies lined with Drift, some extending from beach to cliff-top, as, for example, one between Storre and Lille Taler. Where these reach beach-level and can be examined, they consist of a dark stony clay. One nearly-horizontal bed, under the cliffs of Slotsgavelne, can be followed for about 100 yards, till it sinks below the shingle. It seems to be about 15 feet thick, and most of it is hidden by talus, but one or two rain water gullies had laid bare its upper part, and its junction with the Chalk above. For a few inches below the junction it is slightly streaked: after that, it is a dark tough Boulder-Clay containing numerous stones.

Can all these varieties of Drift-inclusion be accounted for, consistently with the pre-Glacial age of the disturbances? I think that they can.

The Chalk after extensive disturbance would not be left with a level surface. There would almost certainly have been a hill-country such as we find now; and that hill-country would, most probably, have faced the sea in a line of cliffs, such as we now find on all the Chalk-shores which face the Baltic: Rügen, Möen, Stevns Klint. In Glacial times the Drift came. It still lies against the northern and southern ends of the present hill-country, to a thickness which, in places, exceeds 100 feet. It runs up the slopes to their summits, and may be seen capping the highest cliffs. It occupies all the inland country. Thus the Chalk-hills are now overlain by a mantle of Drift, and if at its deposition there was in existence a range of cliffs, it would have sloped up against that range. The present cliffs are indented with valleys, gullies, clefts, some deep and narrow, scarring the cliffs from summit to base; recesses, as will be described hereafter on Sommerspiret; horizontal furrows, where the Chalk overhangs the slopes below. There would be similar hollows in the pre-Glacial cliffs, and the mantle of Drift would fill all. When denudation began, it would proceed to remove this mantle. A stage must come in which the range of cliffs would begin to be exposed again. They would show chiefly Chalk, but much Drift would remain in the valleys and gullies, and in recesses or sheltered grooves of the cliffs. The aspect at such a stage would be similar to the aspect presented now. I think that every variety of Drift-inclusion which we find is accounted for, if we suppose the cliffs that we see to be actually in this stage of the denudation. Former caves and recesses would show on the cliff-face as patches of Drift; former horizontal grooves would appear to be bands; gullies might retain a Drift-lining; while the deeper valleys would again be valleys, but nearly filled with Drift.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 308, fig. 1 (there called section at Forchhammers Pynt).

[2] *Ibid.* p. 309, fig. 2 (section in cliffs near Sandskredsfald).

Papers by Prof. Bonney and myself have shown [1] that in Rügen also the Chalk suffered extensive pre-Glacial disturbance. The Drift-inclusions there are of a different nature, but reasons can be seen. In Rügen they occupy V-shaped trenches, down which brooks run to the sea. The surface of the high ground in Möen is much less extensive: there are no brooks comparable with those in Rügen, and no such V-shaped trenches. The Drift in these Rügen trenches shows beds of clay with intercalated sand. There is no such well-marked stratification in the Möen Drift: at a distance of so many miles, similarity is not to be expected. There are, however, in Möen, indications of bedding or banding in the clay at several points. Also there are, as in Rügen, some indications of a more extensive succession. The Drift at beach-level is almost always clay: at the mouth of a valley called Sandskredsfald, shingle is seen above the clay in well-marked beds, to a thickness of some 60 feet or more; and some shingle is seen elsewhere. Sand is seen over clay in several places, and over the shingle wherever that occurs. Many large boulders are scattered over the sand, and are found even on the highest parts of the hills. The largest of all, called Svantevidsten, about 8 feet in its smallest dimension, lies but a few feet below the top of Aborreberg, the highest point of Möen. Thus here, as well as in Rügen, there seems to be a succession in the Drift.

I made some other observations which seem worth putting on record.

Chalk-slopes rise from the beach to the base of the cliffs some 60 or 80 feet, and in gullies and recesses run up to any further height. At first sight, one would take these for talus-slopes, built up of débris from the cliffs. But they are not talus: the débris on them is only 2 or 3 inches deep; below they are slopes of solid chalk. I first noticed this in rain-water channels; and afterwards in places where the waves have begun to cut into their bases. The lines of flint in them are seen to be continuous and unbroken, as in the cliffs above. At my last visit, it appeared to me that this process of cutting into these slopes, and forming fresh miniature cliffs at their bases, had only begun in the last year or two. Without attempting any hypothetical explanation of these solid regular slopes, I certainly think that they suggest some succession of changes in the relative positions of land and sea. If so, do they not constitute a warning against assertions that denudation since Glacial times must have produced this or that amount of effect? For they remind us of our ignorance as to the times during which denudation has been active or quiescent.

Sommerspiret is a headland crowned with a pinnacle of Chalk. Its southern side, under the pinnacle, is a nearly vertical cliff-face. Over this face are scattered hollows, showing white against a grey weathered surface. There must be a skin of tougher material protecting softer material behind it: wherever the skin has given

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 315 & vol. lvii (1901) p. 16.

way, wind and rain have eaten out a cavity in the softer Chalk. The beds are vertical, the pinnacle being one result of this bedding, so the face may be a harder bed. As erosion proceeds, some hollows will join and produce projections. Like projections and hollows, if existing when the Drift was laid down, would form shelters for it, and when denudation commenced would long preserve remnants. Such may be the explanation of some among the isolated Drift-patches on the Chalk-cliffs.

Möen has sometimes been cited as a parallel to Cromer. In truth, the two are contrasts. At Cromer we see long cliffs of soft Drift containing here and there masses of included Chalk. Möens Klint shows long and lofty stretches of solid Chalk-cliffs, containing here and there appearances which resemble portions of included Drift. However, beyond the Chalk-cliffs, both to the north and to the south, the overlying mantle of Drift forms a bank above the beach which gradually sinks to sea-level. In this Drift, more than a mile away from the Chalk in a northerly direction, may be seen two or three boulders of Chalk measuring several feet in length. One in particular lies obliquely, and has bedded sands attached to it both above and below, quite like some of the Cromer Chalk-boulders. This isolated instance of likeness in the associated Drift serves to emphasize the contrast between the solid continuous chalk-face of Möens Klint and our Cromer cliffs.

The explanation, then, of the seeming Drift-inclusions in Möens Klint, appears to be that the Klint is a range of Chalk-hills, pre-Glacially disturbed, scarped, and eroded, over which in Glacial times a mantle of Drift was laid down. Of that Drift which lay against the scarp we see relics remaining in valleys, as we see Boulder-Clay occupying bays along the Yorkshire coast. It filled pre-existing tunnels, cavities, recesses, and fissures in the shattered and eroded Chalk: in these also relics of it remain. Had the cliffs of Yorkshire been dislocated and shattered as have been those of Swanage and Lulworth, the phenomena of Möen, instead of being unique, might be common on the Yorkshire coast.

Discussion.

The Chairman (Mr. A. Strahan) remarked on a section which had been shown to him in South Wales by Mr. Tiddeman. There, in an inaccessible spot, a band of Boulder-Clay presented a perfect illusion of being interstratified with Coal-Measure sandstones. The clay, as a matter of fact, was lodged on a shelf which had been formed by the weathering-out of a soft bed. The photographs which had been exhibited by the Author well illustrated his contention that there was a contrast between Möen and Cromer in respect of the relations of the Chalk-masses to the Drift.

Mr. A. P. Young thought that the remarkable series of grooves on the surface of the Chalk, to which the Author had called attention, might be compared with structures in the Alps known as *karrenfelder*, said to be due to irrigation by water from melting snows.

We have, in both cases, a series of furrows distributed over the surfaces of soluble rocks, following routes obviously different from those taken by the ordinary watercourses.

Mr. H. B. Woodward commented on the similarity between some of the phenomena described by the Author and those connected with the Chalky Boulder-Clay in East Anglia; and he thought that, if the Author had believed in the great Baltic Glacier his difficulties would have vanished.

Mr. Lamplugh recognized the possibility that patches of Drift might lodge against a pre-Glacial cliff, but thought that the scanty evidence brought forward by the Author was insufficient to warrant the new interpretation which he proposed for the Möen sections, and that the previous explanation of the phenomena by Glacial disturbance was in closer accord with the facts.

Prof. Bonney said that, as he had accompanied the Author on his first visit to Möen, he could testify to the accuracy with which its sections had been described. The Chalk there had, no doubt, been disturbed, but by earth-movements, not ice-thrusts. We might almost as well appeal to the latter to explain the flexures at the Needles or Culver Cliff. He knew the karren of the Alps (mentioned by a previous speaker), but there was little resemblance between these and the furrows on the chalk-cliffs in Möen and Rügen, although both were due to the action of water. The Glacial Drift at Möen occupied cavities in the Chalk, which might indeed have been originated by fissures or dislocations, but had been afterwards enlarged by the action of water—were similar, he believed, to those existing in the Chalk under London. Some of these had been exposed by denudation, and into them the Drift had made its way. While it was quite possible that a pre-Glacial line of cliffs might in places have been disclosed, he would not lay much stress on that possibility, for he thought that what could now be seen was explicable by the sea, as it encroached, laying bare these Drift-filled channels.

Prof. Boyd Dawkins remarked that Prof. Bonney's views were in unison with what he himself knew of the water-passages that occur in the Chalk of this country. Many of these were pre-Glacial, and where Drifts occurred they were swept in. There was, indeed, nothing remarkable in finding Boulder-Clay in cavities in the Chalk, and similarly in the Carboniferous Limestone (as, for example, at the Victoria Cave, near Settle). There was no necessity to invoke the power of ice, or any other such agency, to ram such deposits by sheer dynamical force into the Chalk.

Mr. Whitaker asked whether there was any difference between the Boulder-Clay of the hollows down in the Chalk and that of the massive deposit, and suggested that, if the clay had been carried down by water, or otherwise reconstructed, it ought to differ from the undisturbed clay.

Prof. Garwood said that he was interested in seeing the Author's admirable photographs illustrating the relationship between the Chalk and the Clay in Möen. He did not gather from the Author

whether he attributed the horizontal beds to introduction by water-action from above. It seemed rather difficult to understand how Boulder-Clay, more or less stratified, underlying the Chalk could be brought in from above. If it was washed in from above, the selective action of water might come into play, as suggested by the last speaker, and one of the slides shown certainly suggested this.

The Author, with the Chairman's approval, read the following extract from a letter which he had received from Sir John Evans:—

'It is, I do not know how many, years ago that I visited the island of Möen, in company with the late Prof. Steenstrup. The impression left on my mind by the abnormal contortions of the Drift was that they might, to a great extent, be due to the corrosion and erosion of the Chalk below, by the infiltration of water charged with carbonic acid. The surface of the Chalk in Hertfordshire is remarkably irregular, with deep indentations and numerous pinnacles. Within less than 100 yards of each other, shafts may be sunk through Drift, and the Chalk in one shaft may be 30 or 40 feet below the surface, and in another only 10 or 15 feet. In a shaft about 6 feet in diameter, that I have lately had sunk near Berkhamsted Common, the surface of the Chalk on one side of the shaft is about 6 feet higher than it is on the other.

'On the Great Northern Railway, near Knebworth, there are pipes eroded to a great depth in the Chalk, which must have been formed since Pleistocene times, inasmuch as in the gravels let down in the pipes there are palæolithic implements. If I remember rightly, a similar pipe in the Valley of the Somme, cited by Prestwich, is 90 feet deep.'

He replied to Mr. Horace Woodward that his faith in the Baltic Glacier did not rise to a belief that it could dislocate the Chalk before its own existence. The fissures were made and enlarged before the Drift came which fills them. He thanked Mr. Lamplugh for instances of pre-Glacial fissures on the Yorkshire coast. He had not actually touched the Drift-inclusions half way down cliffs 400 feet high; but some were at shore-level. In reply to Mr. Whitaker, he did not feel sure that re-made Drift was always easily distinguishable, but his own view was that the hollows had in general been filled during the deposition of the Drift.

22. *On the* RELATIONS *of the* CHALK *and* BOULDER-CLAY *near* ROYSTON (HERTFORDSHIRE). By Prof. T. G. BONNEY, Sc.D., LL.D., F.R.S., F.G.S. (Read March 21st, 1906.)

IN a paper read before the Geological Society in 1903,[1] Mr. H. B. Woodward described three sections exhibited in pits on the Chalk-uplands to the south of Royston, which in his opinion indicated that a great ice-sheet, as it advanced from the north, had sheared off large masses of Chalk and left them mixed up with its ground or englacial moraine (the Chalky Boulder-Clay). I am aware that authorities may be cited in support of such an association; but as I have visited more than one alleged instance of it without becoming a convert, and am doubtful whether any British ice-sheet ever extended so far to the south, I venture to state why I am still unconvinced. I carefully examined, in July 1904, the pit lying 'south-west of Newsell's Park and north of Barkway': selecting this because it evidently afforded the strongest support to Mr. Woodward's view, and came away less than ever a believer. Last October I returned thither in company with my friend, the Rev. E. Hill, then but recently back from his third visit to Möen, in order to have the benefit of his experienced eye; and from this pit we went on to that at 'Pinner's Cross, Smith's End, south of Barley.' He took some photographs, which have been useful to me in checking my diagrams; and I may add that, in all important respects, he agrees with the views expressed in this paper.[2]

It will save time to state at the outset that I differ from Mr. Woodward on questions of interpretation rather than of fact; so I shall refer the reader to his paper for a general description of the details, and mention only those on which this interpretation depends. But, before proceeding to them, I feel justified in offering some objections of a more general character.

Mr. Woodward and some other geologists apparently take it for granted that an ice-sheet once occupied the English lowlands about as far south as the Thames Valley; or, in other words, that the Boulder-Clay of that region is the direct product of land-ice. This, however, as we must remember, is only an hypothesis. It may be correct, but that has still to be proved. It involves grave difficulties, and these have hitherto been met by explanations which either are equally hypothetical, or, if true in themselves, are doubtfully applicable to the particular circumstances. To some of these I shall presently refer in connexion with these sections, but think it well to mention a very important one before proceeding further. The

[1] Published in the Quarterly Journal, vol. lix (1903) p. 362.

[2] I failed to find the pit 'north of Reed' on the former occasion, but have seen it since this paper was read. As I expected, it proved nothing. [I went again to the Pinner's-Cross pit last January, and to the Newsell's-Park pit also in April, because at the former date quarrying was being done which gave some promise of discovering another fissure on the more northern side of the pit; work had then ceased, without any definite results.]

Boulder-Clay at these pits, as is usual in the eastern parts of England south of Flamborough Head, is full of more or less well-rounded fragments of chalk which are often striated. This Mr. Woodward cites (like several other authors) as if it proved the action of land-ice. Striations are no doubt frequent on stones which have been transported between such ice and the underlying rock, but they could not often be produced either in ground-moraine (that is, a sub-glacial stony clay) or in englacial material. Even if the latter were sufficiently abundant to make contact between two stones a common occurrence, that contact would usually affect only a very limited surface-area on either of them, and the difference in their rate of movement would hardly be sufficient to produce a scratch of any length. For similar reasons, it is difficult to understand how striations could be made in a ground-moraine, when that is at all thick[1]; but, as every one knows, they are easily produced when a stone held in the grip of ice is rubbed against a rock-surface. Again, a glacier is a much less efficient pebble-maker than moving water. The former can smooth the broader faces of fragments; but can produce only slight effects on the narrower, because of the obvious difficulties in holding them against the grinding surface of rock. I doubt whether the form of a stone shaped only by ice-action will ever be more than subangular. But the larger chalk-fragments which are so abundant as to give an epithet to the Boulder-Clay in the above-mentioned parts of England[2] are true pebbles, most of which are at least subrotund, like those on a sea-beach at the foot of chalk-cliffs. They might also be formed by streams, but fluviatile chalk-gravels are not, so far as I know, common in this country. Thus it is more probable that the chalk-fragments in the Boulder-Clay are seaworn pebbles from a beach; but if so, we are confronted with some difficulties in the land-ice hypothesis, which, as I have referred to them elsewhere,[3] I am contented with mentioning, and that only lest they should be ignored. Enough to say that, as Col. Feilden proved more than a quarter of a century ago,[4] the tidal movements of an ice-foot can striate beach-pebbles which afterwards may be transported to very considerable distances. Any such explanation of the English Boulder-Clay is of course an hypothesis. My point is that the attribution of it to land-ice is at least equally hypothetical, and thus cannot be used as an axiom, on which a logical superstructure can be safely erected.

Mr. Woodward also assumes that an ice-sheet, when advancing, is capable of shearing off and thrusting before it large masses of such

[1] The clay in these East-Anglian deposits is always, so far as my experience goes, sufficiently abundant to keep the stones from coming frequently into contact. Doubtless this would sometimes happen, but even then the scratches would, as a rule, be short.

[2] It covers (intermittently) a large area. I have myself examined it in places from Yorkshire to Essex, and inland to the neighbourhood of Narborough in Leicestershire.

[3] 'Ice-Work' 1896, pp. 164–88.

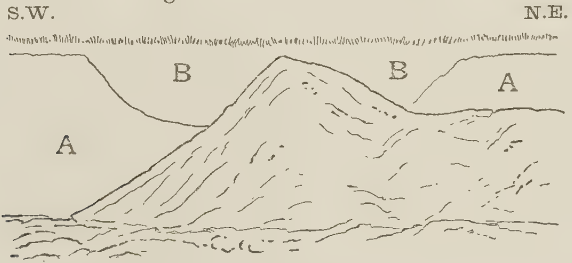
[4] Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 566.

a rock as Chalk. This, again, is only an hypothesis. I have studied the places over which land-ice has passed in several parts of Europe as well as in Canada, and have never been able to find any valid evidence that it has, except perhaps under two very exceptional circumstances, any power worth mention, either to excavate or to break off large masses of rock. It can, no doubt, abrade considerably, but the utmost thrusting work, so far as one can ascertain, which it is capable of doing, is to push before it some morainic material for a short distance, while it has often failed to produce any appreciable disturbance, even on underlying stratified gravel. Before, then, we invoke the shearing-thrust of an ice-sheet, to explain certain relations of Chalk and Drift, we must first prove its ability to accomplish such a task.

(1) Pinner's-Cross Pit, Smith's End.

Turning now to the particular sections, we will take the Pinner's-Cross pit first, as its phenomena are the simpler. Here we find, as Mr. Woodward describes, a few flint-bands, some of them very imperfectly developed, dipping at an angle of not less than 40° roughly towards the north-west. Two at least of these seem somewhat disturbed, as does the Chalk, for it is rather crushed and rubbly; that probably is a consequence of the movements which have bent the Chalk, although it by no means follows that these were due to the thrust of an ice-sheet. But I can add something to Mr. Woodward's description: the Boulder-Clay is 'banked up against the Chalk'[1] not only on its more southern, but also on its more northern side.[2] Fig. 1 is a very rough sketch of what we saw.

Fig. 1.—*Pinner's-Cross Pit.*



A = Chalk-with-Flints.
B = Boulder-Clay; partly masked by talus of clay and soil.
[For minor details see Mr. Woodward's sketch, *op. cit.* fig. 3, p. 364.]

The Boulder-Clay occupies a hollow in the Chalk[3]; the lower part of this is masked by talus, but it is probably saucer-shaped; its breadth is about 5 yards, and the vertical height of the Clay exposed

[1] Quart. Journ. Geol. Soc. vol. lix (1903) p. 365.
[2] W. H. Penning, in Mem. Geol. Surv. 'The Geology of the N.W. Part of Essex & the N.E. Part of Herts, &c.' (1878) p. 7, says that the Boulder-Clay occupies a hollow in the Chalk.
[3] This disposes of Mr. Penning's difficulty referred to, *op. cit.* p. 372.

about 4 feet, part, if not all, of the uppermost foot being surface-soil. Near A, on the left hand, are traces, little more than smears, of clay which might well be produced by muddy water percolating from above along chinks in the rather disturbed Chalk. So this hollow is a saucer or a trough. It is not easy to see how an ice-sheet could have scooped out either. The former, I presume, would require a gyratory action, after which the ice in melting mood must have made restitution by filling up the hollow with Boulder-Clay; the latter would have to be the channel of a subglacial stream which, however, did not transport any big pebbles. Another difficulty I leave for the present, since it exists also at the second pit.

(2) Pit south-west of Newsell's Park.

Here, as Mr. Woodward has described, the rather infrequent flint-bands dip roughly towards the north-west, at a less steep angle than at Pinner's Cross, and the trace of a shear-plane can be seen in the more southern wall of the inner part of the pit.[1] That steepens on approaching the floor, till it makes with this an angle of about 50°, and the rock adjoining it, for a thickness of perhaps 2 inches, has a slightly muddy aspect. That, however, might be due only to greater dampness, but as the point was not important I did not test it by analysis. The clayey patches on the wall of the pit still remained, though the patch of 'brown earth with chalk [fragments]' had, I think, suffered a little in the interval between Mr. Woodward's visit and mine (and again between the latter and our recent one), but I verified its presence and found traces of two other smears of similar material running up the wall, to a height of about 8 feet from the floor. I saw nothing to suggest that the earthy material had been 'nipped up' between masses of Chalk, and its mode of occurrence was suggestive rather of its having trickled from above, down some crack in the slightly-disturbed Chalk-mass.

The most remarkable feature, however, in the pit is the Boulder-Clay which is seen beneath the Chalk rather nearer to the entrance of the pit, apparently filling an arched cavity,[2] roughly 10 yards in length and rising about 4 feet from the floor. I could find nothing to suggest that the overlying Chalk was in any sense a transported boulder, or that the Boulder-Clay[3] had been squeezed into its present position, or anything in the relations of the two calling for the thrust of an advancing ice-sheet.

The following explanation, which Mr. Woodward does not consider, seemed to me far more simple: that the Boulder-Clay has filled a cavity which already existed in the Chalk, though it may

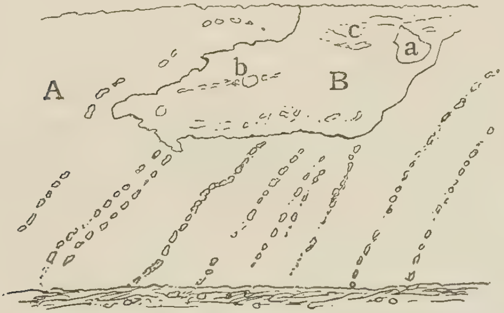
[1] See figs. 4 & 6, pp. 366–67, vol. lix (1903) of this Journal.

[2] On the occasion of my first visit, talus concealed the more eastern end, but this was clear at my second one; the Chalk overhung the Clay (apparently with a natural surface) for at least a foot, and seemed to be descending behind it.

[3] It must lie below the curved shear-plane, and would accordingly require a second big slab of chalk to be thrust over it. But at my second visit the surface of the Chalk overlying the Clay seemed to slope behind the Clay in more than one place. The N. and S. in Mr. Woodward's diagram must be understood as used in a general sense, N.W. and S.E. being nearer the fact.

have been subsequently enlarged; such is the explanation of the relations of Boulder-Clay and Chalk in the cliffs of Möen, as we maintained in 1899.[1] That there are such cavities[2] is distinctly proved in the Island of Rügen. We described some in pits at the back of Sassnitz, on the hill-slope above the town.[3] But the chalk-cliff rising from the shore to the north of the bathing-place affords an even closer parallel.[4] The appended diagram (fig. 2), although

Fig. 2.—*Section in the cliff north of the bathing-place, Sassnitz (Rügen).*



A = Chalk-with-flints. B = Boulder-Clay, as described in the text. (*a*) Piece of chalk, marked '? if *in situ*.' Probably it was, for a very rough sketch made the following year (1899) shows the outline of the cavity to be still more like a foot cut off just above the ankle. (*b*) A streak and a lump of chalk; (*c*) more sandy and stratified hereabouts. The length of the part sketched measures about a dozen yards.

not pretending to be very accurate, for it had to be drawn from the adjoining beach, may save a long description. We examined the section again in 1899, when the shape a little more resembled that of a foot in a stocking, and the small hollow at the bottom was more conspicuous and pointed forward instead of backward. The cavity was a little over 12 yards long, was filled with a Boulder-Clay generally resembling, but not quite identical with, the ordinary grey Boulder-Clay of the district, which contained one fair-sized block and some smaller streaks of Chalk,[5] more especially in the lower part, and became a little more sandy in the upper.[6] The neighbouring Chalk, as shown by the flint-bands, not only dips at a rather high angle, but is locally much contorted. It is impossible, as a study of the diagram will prove, to explain this enclosure of Boulder-Clay, by either faulting or thrusting during Glacial

[1] Quart. Journ. Geol. Soc. vol. lv, p. 305, &c.

[2] They are of course very similar to those which supply water in several parts of England, and are commonly called 'fissures,' but I avoid this term as slightly misleading.

[3] *Op. cit.* pp. 313, 314.

[4] *Ibid.* p. 313; & vol. lvii (1901) p. 9.

[5] Flints are common, but there are also some 'Scandinavian' stones.

[6] The cliff was about 7 yards high, and the ground, if I remember rightly, rose at the back. Both Boulder-Clay and stratified Sand occur in the vicinity.

conditions.[1] It must be a filled-up cavity, such as are found in both the Danish and the German islands, but are commoner in the former, and a section across the 'foot' of this Rügen cavity at right angles to the plane of the paper might give such a one as we find in the pit near Newsell's Park. Mr. Penning's diagram,[2] indeed, represents Boulder-Clay occupying a hollow in, or banked up against, the upper surface of the Chalk (his sketch is incomplete on the more southern side). Even if the woodcut be an 'interpretation-section' (I expect that Mr. Penning drew what he saw), the Boulder-Clay must have been in existence in that position. This clay, though not exactly above that mentioned in the text, which is not shown in the diagram, is said to be 'at the S. W. corner' of the pit, and cannot be more than a few feet away.

We have yet to consider the difficulty presented by both localities to the interpretation put forward by Mr. Woodward:—

> 'Higher portions of débris-laden ice overrode lower portions that were arrested by inequalities in the ground,' and 'to the thrust or long-continued pressure of ice along shear-planes at higher levels against the crest of the scarp we may attribute that belt of disturbance which occurs at elevations of 387 and 400 feet on the east and 535 feet on the west.' (*Op. jam cit.* p. 371.)

Hypothesis again seems active in the earlier part of this quotation; while in regard to the latter I agree with Mr. Jukes-Browne that for ice to have produced this disturbance along a line over 5 miles long 'seems a large order,' venturing also to add that the contour of the ground ought to afford some hold to this aggressive ice-sheet, or else it would slide or crawl over the surface without more than a little superficial scraping or rubbing. How, then, are these pits, related to this contour? Outside the one at Smith's End, which is just within the 400-foot contour-line, the slope of the ground towards the north is very gentle for about 100 yards, afterwards falling rather more steeply to the 300-foot line, on the eastern and the western side: its descent towards the north being still very gentle, for the village of Barley stands on the slightly-shelving top of a shoulder, projecting to the north between two shallow valleys of which the eastern is the more strongly marked. The Newsell's-Park pit is on a very gentle slope, which descends in a generally-northward direction from the 500-foot contour-line; and, although this steepens a little after a time, especially on the north-eastern side, it is always slight. Towards the north-west the ground again rises, a change which would somewhat impede the advance of the ice-sheet. If, then, the present contour of the ground bears any resemblance to that which it had during the Glacial Epoch (and to assert the contrary would be another appeal to hypothesis), the ice could not get such hold of the ground as would enable it to scoop at Smith's End or to shear off the requisite masses near Newsell's Park. I submit, therefore, that

[1] After careful examination of the sections of Möen and Rügen, I am unable to understand how any geologist accustomed to careful work in the field can explain the disturbances of the Chalk and its association with the Glacial deposits by the thrusting action of an ice-sheet.

[2] 'The Geology of the North-West Part of Essex, &c.' Mem. Geol. Surv. 1878, p. 8, fig. 2.

even if Boulder-Clay can be proved to be the product of an ice-sheet, and the latter to be capable of shearing off and disturbing large masses of Chalk, these sections, so far from being explicable by that process, are quite the contrary.

Discussion.

Mr. H. B. Woodward said that he was pleased to learn that the Author found no serious fault with his facts; they appeared to differ, however, with regard to the amount of mechanical disturbance visible in the pit at Pinner's Cross. He remarked that the chalk-pebbles which characterize the Boulder-Clay might well have been derived from a land-surface of Chalk, as the Chalk weathers into a rubble of rounded fragments. He admitted that his explanation of the disturbances depended upon a belief in the land-origin of the Chalky Boulder-Clay. To that belief he had been wedded for many years. The mode of origin was supported by the general uniformity and character of the Boulder-Clay over wide areas in East Anglia and the Midland counties, varied as its composition was by local ingredients from the formations over which the ice moved. It was indicated also by the frequently-disturbed state of the subjacent strata. He referred to a noteworthy proof of the land-origin observed in cuttings of the Great Central Railway.[1]

Prof. Boyd Dawkins said that the point laid before the Meeting seemed to be rather a matter of opinion than of facts. The Author might be right in this case, but the effects of the pressure of ice on the surface of this country were undoubted. There had been no movement of ice from the low to the high ground, but there had been from the high to the low. The crumpling shown here was not due to anything that took place on land, but icebergs impelled by wind and waves would delve up the shore on which they stranded.

The evidence as to the physical configuration of the district was of great interest, the difference between the gentle slope of the Chalk in the Cambridgeshire area and on the borders of Essex, and the steep scarps of the North and South Downs, being doubtless due to Glacial phenomena.

The Rev. Edwin Hill said that he agreed with the Author's views. He had thought that Mr. Woodward's paper had built high on a small foundation. It attributed to ice-sheet thrust a roll in the Chalk, on account of some included clay, and that clay, on account of the roll in the Chalk: then, on these as foundation, built an ice-sheet.

Mr. Lamplugh remarked upon the Author's objection to the land-ice hypothesis, and suggested that, if the evidence for this hypothesis in Eastern Britain was considered in its entirety, the Author's difficulties in accepting Mr. Woodward's interpretation of the Royston sections would vanish. As in every other result attained in geology, it was quite possible to pick out points difficult

[1] See Geol. Mag. 1897, p. 103.

of explanation; but, in this case, these were altogether disproportionate to the mass of positive evidence obtained from many converging lines of investigation. In the particular instance under discussion, it was necessary to remember that the border of the Eastern Drift-sheet in Britain, from Banff to Norfolk, was characterized by the occurrence at intervals of huge displaced masses of the solid strata that were often actually incorporated with the Boulder-Clay; and similar masses were also found in the prolongation of this belt across the Eastern Midland counties of England. With this definite evidence for the breaking-up of the underlying strata by Glacial agency, Mr. Woodward's interpretation of the Royston phenomena was in perfect agreement; and, since the general evidence for the former extension of land-ice over the same region was so weighty, it was surely most reasonable to assign the disturbances in question to the influence of land-ice.

The Author, in replying to Mr. Woodward, said that he was well acquainted with the rubbly weathering of the surface-Chalk and the making of pebbles, but could not admit that those so common in the Boulder-Clay had been produced by the former action. They were true waterworn pebbles. He did not agree that the railway-section quoted by Mr. Woodward could only be explained by the action of land-ice. He did not, of course, deny that flexures and dislocations existed in the Chalk near Royston and elsewhere, but did deny that these could be ascribed to the action of land-ice. He could not even agree with Prof. Dawkins that the slopes near Royston showed any signs of ice-action: they became steeper farther west, and the difference in hardness and dip would account for their being more gentle than in the southern scarps of the North Downs. Mr. Lamplugh had asserted that difficulties would vanish if an ice-sheet were once accepted. That might be; for the speaker would find many difficulties vanish in theology, if he could accept the leadership of an infallible guide—but unfortunately he could not. Mr. Lamplugh complained that he raised small difficulties, and did not view the subject as a whole. Why, he had been raising large-scale difficulties for years, and could not get them answered! He had asked how land-ice could get to England from Scandinavia over the wide and deep channel which contours the latter country, and the best reply that he got was that there was a sort of 'clearing-house' at the Dogger Bank, or that the channel was post-Glacial! He had asked how, if distributed by land-ice, Shap boulders crossed the ice coming from the Cheviots and Scotland, and Arenig boulders crossed those from Criffel and the Lake District—and the only answers given ignored the physical properties of ice. He was personally acquainted with most of those transported masses to which Mr. Lamplugh had referred, but could not accept his interpretation of them, and deemed it unscientific, either to ignore difficulties which really existed, or to bow down to authority. With arguments of that style he was familiar enough, but they were not suited for use in the place where he was speaking.

23. *The* Phosphatic Chalks *of* Winterbourne *and* Boxfo (Berkshire). By Harold J. Osborne White, F.G.S., an Llewellyn Treacher, F.G.S. (Read April 25th, 1906.)

Contents.

I. Introduction.

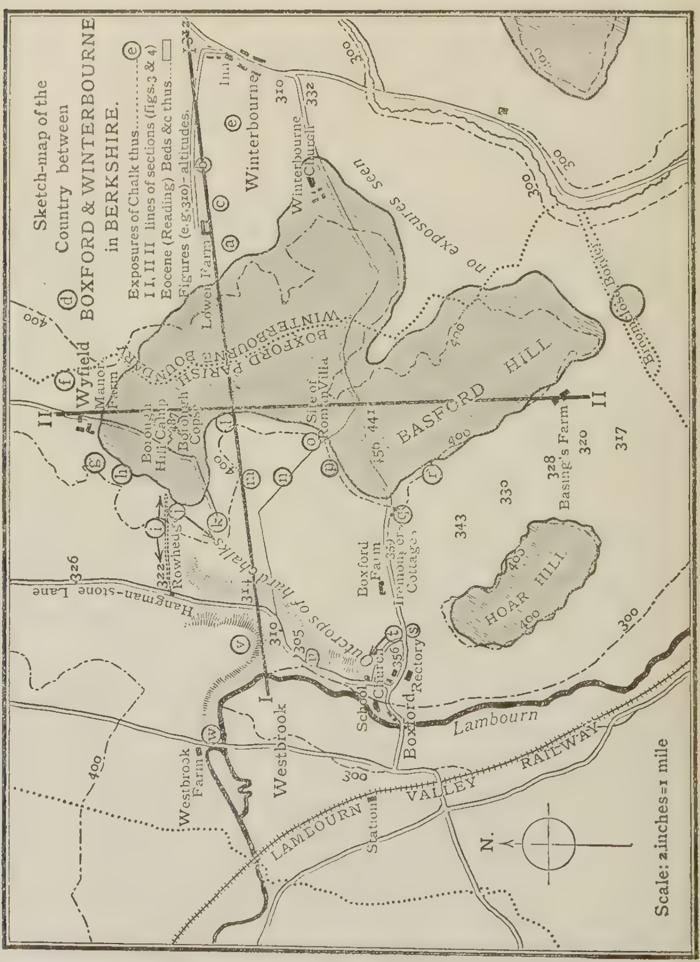
In the latter part of July 1905 we remarked, among the fossils exhibited in the recently-founded Museum at the Cloth Hall, Newbury, a group of guards of the belemnoid *Actinocamax granulatus* (Blainville), labelled 'Winterbourne'—the name of a village $3\frac{1}{2}$ miles to the north-west of the above-named town. To us, these specimens were objects of more than usual interest, inasmuch as our examination of the Upper Chalk in the western part of the London Tertiary Basin, so far as it then extended, had shown us (1) that *Actinocamax granulatus* was a rare fossil in that area; (2) that it was there confined to beds of the *Marsupites*-Band and of later age; and (3) that such beds, although well-developed to the south of the Kennet, were cut out, by the Eocene overstep, to the north of that river, along a line passing 2 or 3 miles south of the parish of Winterbourne. Assuming the guards to be correctly labelled, they seemed to indicate the existence of an outlying mass of *Marsupites*-, or newer, Chalk rather rich in belemnoids, within a tract of country where the Eocene deposits were known to be generally in contact with some part of the older, *Micraster cor-anguinum*-Chalk; and as we had but recently given some attention to just such a mass in the shape of the Phosphatic Chalk of Taplow, the possibility of the recurrence of phosphatic conditions near Newbury at once presented itself to our minds.

On our making enquiry of the Honorary Curator, Mr. Frank Comyns, M.A., he informed us that the specimens of *Actinocamax* had been presented by Miss M. Baylis, of Wyfield Manor, Boxford, a lady with whom he was so good as to place us in communication. We visited Boxford in August, when Miss Baylis kindly showed us a small but interesting collection of local Chalk-fossils, and described the position of the excavations whence they were derived. The examples of *Actinocamax* (of which the collection contained about a dozen) had all been obtained, we were informed, from a single working; and this proved to be a small, disused field-pit, a quarter of a mile north-west of Winterbourne Church, and visible from none of the neighbouring roads. Though the face of the pit was stained by rain-wash, it could be seen at a glance that flints, which abound in most of the other excavations in the district, were here

either very scarce, or—as was later found to be the case—entirely wanting; and a closer inspection revealed the brown granules, hard bands, nodules, and other evidences of phosphatization.

The pit was revisited by both of us on three or four occasions during the ensuing autumn, and some attempt was made to ascertain

Fig. 1.



the extent of the phosphatic beds; but little further information was obtained until the winter, when the withering of the vegetation and the ploughing of the fields revealed a number of white patches in the soil, marking the spots where Chalk lay near the surface. An examination of these rubbly patches and of the disintegrating rock beneath them, has enabled us to work out the sequence of the

strata in a Phosphatic-Chalk group not less interesting than that of Taplow.

The principal observations made in the course of this investigation are recorded in the following pages.

The piece of country with which we are chiefly concerned forms part of an irregular, southward-pointing spur, or inter-vale, lying in the angle between the convergent valleys of the Lambourn and the Winterbourne, and further defined, on the west, by the dry combe of Hangman-stone Lane, which joins the Lambourn Valley at Boxford. The crest of this spur stands between 150 and 180 feet above the floors of the rather sharply-incised valleys just mentioned, and, although somewhat 'accidented' near its southern end, rises persistently northwards, and eventually merges into the general dip-slope of the Berkshire Downs.

The common boundary of the parishes of Winterbourne and Boxford traverses the spur longitudinally, keeping somewhat to the east of the line of highest ground. Near Winterbourne village this ''tween-stream' block consists of Upper Chalk surmounted by outlying masses of sandy and clayey Eocene (Reading) strata, the largest and thickest of which outliers forms the rounded eminence of Borough Hill, and the gravel-capped plateau of Basford Hill to the south of it. The prevailing dip of the Chalk and Eocene deposits hereabouts is a gentle one to the south-east, but there are local and discordant dips in the Chalk—some of considerable strength—which are not shared by the newer strata.

The several exposures of Phosphatic and other Chalks about to be described or noticed are indicated in the accompanying sketch-map (fig. 1, p. 500) by the letters (**a**) to (**w**). These will be dealt with in alphabetical order, but in two groups: those from (**a**) to (**e**) inclusive falling under the heading of Winterbourne exposures; and the remainder under that of Boxford exposures.

II. Exposures in the Parish of Winterbourne.

(a) Pit a quarter of a mile north-west of Winterbourne Church.

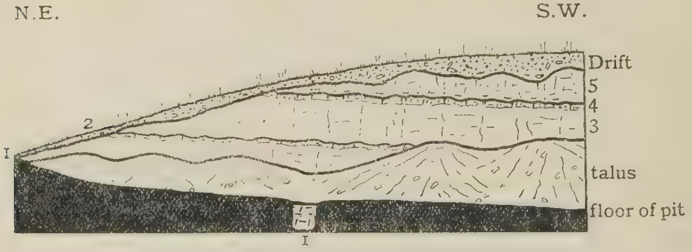
Originally this pit had a maximum depth of 15 feet, but the talus has now mounted halfway up the face. The disposition of the principal lithological divisions seen on its southern side, and in a trial-hole opened by us in its floor, is shown in fig. 2 (p. 502). The dip is about 3°, to the south-west, or nearly so.

Commencing at the bottom:—The chalk in the trial-hole is white, with scattered brown granules, and is, for the most part, friable, coarse-grained, and harsh to the touch, but contains firm to hard lumps without definite shape or limits. Obscure branching bodies of slightly-greyish tint and of coarser texture occur in places, and small hard nodules (measuring up to a third of an inch in diameter).

with a rich brown vermiculate crust and greyish-green nucleus, are scattered sparingly through the rock.

The lowest chalk visible in the main exposure is similar to that in the trial-hole, save that the hard lumps are much scarcer, the brown grains and nodules more numerous, and the nodules attain a greater size (three-quarters of an inch).

Fig. 2.—*Section on the south side of pit* (**a**), *about a quarter of a mile north-west of Winterbourne Church.*



[Vertical scale: 1 inch =20 feet.]

Near the top of bed (1) the hard lumps reappear in force, and the brown granules, increasing in number, impart to the rock the characteristic dusty-grey tinge of Phosphatic Chalk. Neither here nor in any other part of the section, however, do the beds contain nearly so great a proportion of phosphatized material as the brown chalks of Taplow and Lewes.

The ascertained thickness of bed (1) is $8\frac{1}{2}$ feet.

The chalk above described passes up into a hard, yellowish-green, nodular rock—bed (2)—about 3 inches thick. This band is, in places, sufficiently homogeneous to have acquired a rectangular jointing; elsewhere it consists of rounded lumps and nodules, separated by rather softer chalk containing many small brown nodules with furrowed, perforate crusts. Impressions of sponges are common.

The succeeding bed (3) is a white to pale-grey, exceedingly-gritty, friable chalk, between $4\frac{1}{2}$ and $4\frac{3}{4}$ feet thick, and somewhat widely jointed. Oyster-shells form no small proportion of the bed, and the weathered surfaces are rough with their remains. Brown nodules ranging up to three-quarters of an inch in diameter, and brown angular concretions of smaller size are abundant; but there is a decided falling-off in the proportion of brown granules. Towards the top this chalk becomes firmer, assumes a lumpy character, and passes, sometimes insensibly, sometimes rather abruptly, into the overlying hard band.

The hard chalk of bed (4) is a tough limestone, 6 to 9 inches thick, of a yellow or greenish-yellow hue, but stained dull red in places by iron-oxide, which occurs in subspherical pseudomorphs after pyrites. Greenish nodules (to 3 or 4 inches in diameter) with brown corrugate crusts, and angular concretions (under half

an inch in diameter) are scattered through the rock, which, in its less compact portions, is even more harsh and gritty to the touch than the chalk below. In the midst of the rock the green nodules are firmly welded to their matrix; near the top they may often be detached with little difficulty. The appearance of this chalk recalls that of the Chalk Rock. Where hardest, the rock is rather closely and rectangularly jointed, and its gnarled, undulate, well-defined top bears the impressions of sponges of the *Ventriculites*-type; it is well-encrusted with adherent valves of *Ostrea*, *Spondylus*, and *Plicatula*; and is covered with a faintly-glossy brown wash of phosphate, which penetrates to a depth of a quarter of an inch or more. Dendrites of manganese-oxide occur on the joint-surfaces.

The chalk of bed (5)—seen for about 4 feet in the highest part of the section—is firm and white, or pale greyish-white, with black specks. It is closely jointed into small cuboidal or flaggy blocks, and much stained by earthy wash from above. Very harsh and gritty in its lower parts, it gradually becomes soft and fine-grained upwards, and samples from the top are hardly to be distinguished from ordinary chalk by the naked eye. Greenish-yellow nodules with brown coats and the little angular concretions are common in the lowest 18 inches, but become scarce above; and brown granules, though common enough in the lowest 6 inches, are elsewhere much less apparent than in the beds lower down in the section.

The Chalk is covered by a sandy loam, with flint-nodules and broken flints, which descends into shallow pockets. At the bottom of this Drift there are a few unworn flint-nodules, of elongate form, which have doubtless been derived from the Chalk formerly intervening between the highest beds of the section and the base of the Reading Series.

Microscopic features.—When broken down with a brush in water and washed clear of the fine calcareous mud, the softer chalks of this section yield a bulky residue, consisting of the following materials:—

(1) Prisms of *Inoceramus*-shell. The great majority are unphosphatized; larger fragments of the shell occasionally are partly silicified. This material is most abundant in the residues from bed (3); least so in those from the upper part of bed (5).

(2) Foraminifera: frequently phosphatized and of a pale to rich dark-brown colour, often with a high polish. The phosphatized examples are referable chiefly to the Textulariidæ and Globigerinidæ, and usually measure between 0·1 and 0·2 millimetre in diameter. The calcareous examples are mostly of the Rotaliidæ, and are more numerous and generally of greater size (0·3 to 0·6 mm.) than the phosphatized. Subspherical objects, which appear to be detached cells of foraminifers, are common.

(3) Angular chips of scales, bones, and teeth of fish: honey-coloured and transparent or translucent, to brown or flesh-coloured and opaque. These exhibit all those features that were noticed by Mr. A. Strahan [1] in the fish-remains of the Taplow Chalk. Most of them measure between 0·2 and 1·0 millimetre in length.

(4) Irregular, angular, and subangular lumps and platy pieces of calcite, dull white and translucent. The plates probably are mainly fragments of oyster-shell, which yield precisely similar débris when brayed. Usually under 1·0 mm. in diameter. Light-brown and flesh-coloured, partly or wholly phosphatized materials of the same forms also occur.

(5) Rod-like objects: smooth, cylindrical, or tapered—probably spines of echinoids.

(6) Coprolites of small fishes, echinoids, and other animals: light to dark-brown ovoid bodies, occasionally of convolute or strangulate aspect, and frequently polished. These commonly range from 0·2 to 1·0 mm. in length. They are rather scarce in the residues from bed (1); more common in those from bed (3); and most common in those from the lowest part of bed (5), where they attain their greatest size.

(7) Tests of Entomostraca. These are rare, and have not been recognized in the phosphatic state.

(8) Quartz, in subangular and well-rounded, yellow or colourless grains. Not uncommon in bed (3); prominent in the residues from bed (5). They rarely exceed 0·5 millimetre in diameter.

(9) Black granules—apparently of iron-oxide—minutely mammillated. These occur throughout the section, being most noticeable in the upper part of bed (5). Size:—0·25 to 0·5 millimetre.

(10) Rich brown, polished, phosphatic concretions of rounded or botryoidal form. Usually under 0·3 millimetre.

(11) Dull green grains, imperfectly rounded; noticed only in residues from the lower part of bed (5).

The constituents just enumerated are mentioned, as nearly as may be, in their order of abundance. It should be observed that the character and relative proportions of the phosphatized materials are much more constant than those of the calcareous.

When the brown casts of foraminifera and the little brown concretions (No. 10) are treated with hydrochloric acid, a variable but usually small proportion is found to consist of a pale to dark-green, opaque or translucent mineral (presumably glauconite), with a thin veneer of phosphate. These disguised glauconite-concretions and pseudomorphs are most common near the base of bed (5) in this

[1] Quart. Journ. Geol. Soc. vol. xlvii (1891) pp. 359–60 & figs. 2–6, p. 366.

section. They occur in all the Phosphatic Chalks of this neighbourhood, as well as in those of Taplow and Lewes.[1] It is noteworthy that, of the foraminifera, the Globigerinidæ are by far the most frequently preserved in this way, although casts of a *Cristellaria* (probably *Cr. rotulata*, Lam.) are prominent in some samples.

Faunal Succession.—The most important fossil observed in bed (1) is *Marsupites testudinarius*, which is represented, as usual, by scattered plates and brachials. Remains of this crinoid occur throughout the bed, but are most common between 1 and 2 feet below the top, where there are probably about a dozen of the plates per cubic foot of chalk.

In the nodular band (2) the same form occurs, and with it an abundance of *Ostrea vesicularis* and of bits of *Inoceramus*, remains of *Spondylus spinosus* (?), and casts of sponges.

The friable chalk of bed (3) swarms with remains of *Ostrea vesicularis*, *O. Wegmanniana*, and other oysters, and pieces of *Inoceramus* also are very abundant. In the lowest part of this bed *Marsupites*-plates are still fairly common, but they become scarce about 8 or 9 inches up, and have not been found higher than $2\frac{1}{2}$ feet above the base. At the horizon where *Marsupites* becomes scarce, we obtained one very slender guard of *Actinocamax verus*, and noted the first appearance of *A. granulatus*.

The guards of the latter belemnoid are sparingly represented in the succeeding 4 feet of bed (3), and appear to be evenly distributed therein. They are rather below the average size, show a feeble but distinct granulation, and have an alveolar depth between one-fifth and one-seventh of their length. Though usually broken, they are rarely much decayed. *Echinocorys scutatus*, which we have seen only in small fragments in the lower beds, is often well-preserved here. Most of the examples collected by Miss Baylis and by us are of the slightly-blunted pyramidate or angulate form and medium size (length = 60, height = 42 mm.) usually met with in the *Marsupites*-Band in Berkshire, North Wiltshire, and North Hampshire; but in the upper half of this bed a smaller and more squat mutation of the pseudo-*pyramidatus* variety is occasionally seen. *Micraster cor-anguinum* var. *rostratus* is common in the higher layers; teeth of *Corax*, *Lamna*, and *Oxyrhina* are not infrequently encountered; and *Spondylus latus* occurs throughout.

In the yellow rock-band, bed (4), *Actinocamax granulatus* and *Echinocorys scutatus* become very common. Here the former is more markedly granulated, but can rarely be extracted in an other than fragmentary condition. The pyramidate variety of *Echinocorys scutatus* present in the softer chalk below is almost completely replaced by stunted forms, which are better seen in the succeeding bed (5). Casts of the sponges *Ventriculites radiatus*, *V. infundi-*

[1] See A. Strahan, Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 362, & vol. lii (1896) p. 465.

buliformis, and *Coscinopora quincuncialis* are very common, and one specimen of *Offaster pillula* was obtained.

Abundant as are the remains of *Actinocamax granulatus* and *Echinocorys scutatus* in bed (4), they form but the forerunners of the swarms which come in at the base of the succeeding division (5). The guards or tests of these animals occur at intervals of a few inches all along the face of the pit at that horizon, and it is no uncommon experience to find three or four of each almost in contact. They lie most thickly upon, or within 3 inches above, the uneven, oyster-encrusted pavement at the top of the rock-bed (4). We estimate the remains of *A. granulatus* to be fully twice as abundant in the lowest 6 inches of bed (5) as in any band of the same thickness in the Upper Brown Chalk of Taplow Court.[1] Their granulation is, as a rule, very pronounced; and the ratio of the depth of their cavities to their total length ranges from 1 : $4\frac{1}{2}$ to 1 : 6. Some are distinctly quadrate in section; and one imperfect guard, with a deep, steep-sided, quadrate alveolus, is probably referable to *Actinocamax quadratus*. All are partly corroded by soil-water, but the bulk of them seem to have been complete at the date of deposition; and the undecayed portions of the surface of the broken specimens show no obvious signs of attrition.

Echinocorys scutatus is represented in a nicely-graduated series of stunted forms, to the extremes of which the terms 'somewhat inflate-pyramidate' and 'very depressed ovate' may be fitly applied. The average measurements of the test are: length = 48, height = 34 mm., and we have only two examples the dimensions of which greatly exceed or fall far short of these. One of them, of subgibbous form, measures, in length = 67, height = 45 mm.: the other, of a flattened ovate shape, measures, in length = 44, height = 26 mm.

The general facies of the species here is quite distinct from that presented in the higher parts (D and E)[2] of the Taplow Phosphatic Chalk, although the rarer, depressed, form noticed there falls naturally into the Winterbourne series. The tests of *Echinocorys* here are usually in a very brittle state, crumbling on removal from the chalk, and leaving more or less perfect internal casts, which not seldom contain a decomposed pyrite-concretion.

Offaster pillula is common where the remains of *Actinocamax* and *Echinocorys* are most abundant. It exhibits no abnormalities.

Actinocamax, *Echinocorys*, and *Offaster* all become scarce at about 1 foot above the base of bed (5), and have not been found in the upper half of that division, which, indeed, has yielded few megascopic fossils besides *Ostrea*, *Pecten cretosus*, *Spondylus latus*, and *Rhynchonella plicatilis*. Casts of the two last-named fossils occur in the angular flints of the overlying Drift.

The names of the fossils identified in the several beds of this section are tabulated on the following page.

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 472–75.
[2] *Ibid. loc. cit.*

List of Fossils from Pit (a).

× = observed occurrence; c = common; vc = very common. Beds	1.	2.	3.	4.	5.
Corax falcatus, Ag.	...	...	×		
Corax pristodontus, Ag.	...	...	...	×	×
Lamna appendiculata, Ag.	c	...	c	...	c
Oxyrhina Mantelli, Ag.	...	...	×	...	×
Actinocamax granulatus (Blainv.)	...	...	×	c	vc
Actinocamax quadratus? (Defr.)	...	...	...	...	×
Actinocamax verus, Miller	...	...	×		
Inoceramus Cuvieri, Sow.	c	c	vc	c	c
Lima Hoperi (Mant.)	...	...	×		
Ostrea hippopodium, Nilss.	...	...	×	×	c
Ostrea Normaniana, d'Orb.	...	...	×	...	c
Ostrea vesicularis, Lam.	c	c	vc	c	c
Ostrea Wegmanniana, d'Orb.	c	×	c	×	c
Pecten cretosus, Defr.	...	...	×	...	c
Plicatula sigillina, S. P. Woodw.	...	...	×	c	vc
Spondylus latus (Sow.)	...	...	c	×	c
Spondylus spinosus? (Sow.)	...	c	...	×	
Teredo amphisbæna, Sow.	...	...	×		
Kingena lima (Defr.)	...	...	...	...	×
Rhynchonella plicatilis (Sow.)	...	...	×	×	×
Rhynchonella reedensis, Eth.	...	...	×		
Terebratulina striata (Wahl.)	...	...	...	...	×
Bathocypris silicula (Jones)	×				
Cythereis ornatissima (Reuss)	×	...	×	...	×
Cytherella Muensteri (Römer)	×				
Cytherella ovata (Römer)	×	...	×		
Cytherella Williamsoniana, Jones	×	...	×		
Paracypris siliqua, J. & H.	×				
Cidaris sceptrifera, Mant.	...	...	...	×	
Helicodiadema fragile (Wilt.)	×				
Echinocorys scutatus, Leske. Ovate forms	..	...	...	c	vc
Echinocorys scutatus, Leske. Pyramidate forms	?	...	c	c	vc
Micraster cor-anguinum (Klein)	×	...	c	...	×
Micraster cor-anguinum (Klein) var. *rostratus*	...	...	c	...	×
Offaster pillula (Lam.)	...	...	...	×	c
Asteroidea	×	...	×	...	×
Bourgueticrinus	×	...	×		
Marsupites testudinarius, Schloth.	c	×	×		
Parasmilia centralis (Mant.)	...	...	...	...	×
Porosphæra globularis (Phill.)	×	...	×	...	×
Porosphæra patelliformis, Hinde	×	..	×	...	×
Porosphæra sp.	×	...	×		
Coscinopora quincuncialis (T. Smith)	...	×	...	×	
Ventriculites infundibuliformis, S. Woodw.	...	...	...	×	
Ventriculites radiatus, Mant.	...	...	...	×	
Serpula sp.	...	...	...	...	×

Following the classification now generally accepted in this country, we group the beds zonally in this wise:—

Bed 5...... }
Bed 4...... } Zone of *Actinocamax quadratus*.

Bed 3...... }
Bed 2...... } Zone of *Marsupites testudinarius* (*Marsupite*-Band).
Bed 1...... }

Among the features of zonal interest possessed by this little section, one notes the shortness of the interval between the Chalk yielding remains of *Marsupites* and that containing *Offaster pillula*. Dr. A. W. Rowe has shown[1] that the width of this highest division (barren of *Marsupites*) of the *Marsupites*-Band varies from 15 to 20 feet in the coast-sections of Dorset and Sussex. Here it is under 3 feet. Part of this shrinkage is doubtless accounted for by the attenuation which the *Marsupites*-Zone, as a whole, undergoes in Berkshire and North Wiltshire, but it is highly probable that the general thinning was aggravated in the neighbourhood of Winterbourne.

It will be observed, also, that *Actinocamax granulatus*, though associated with *Marsupites* in bed (3), appears just where that crinoid is dying out, and does not become common until the base of the *Actinocamax-quadratus* Zone is reached. The two forms occur together in the Phosphatic Chalk of Taplow, about 30 miles to the east-north-east, and in the normal Chalk of Surrey, Kent, and Yorkshire. The relatively-late appearance of *A. granulatus* here, however, is in accordance with the facts observed in other places in the western part of the London Basin: for the three poor sections of the higher part of the *Marsupites*-Band, and the single workable exposure of normal *quadratus*-Chalk with which we are acquainted in that area, all yield this species, though sparingly; while in only one of the vastly-greater number of *Marsupites*-yielding sections has this fossil been forthcoming. The zonal distribution of the species in this part of the country seems to be much the same as in the coastal parts of Sussex and Dorset.

The top of the pit above described lies between 30 and 40 yards distant from, and 8 to 10 feet lower than, the boundary of the Reading Beds of the Borough-Hill outlier on the south-west. Assuming that the observed dip (of 3°) in that direction is maintained as far as the boundary just mentioned, there is room for about 15 feet of Chalk between the Eocene base and the top of the pit. Adding this 15 feet to the sum of the measurements of beds (4) & (5), we obtain 20 feet as the total thickness of the *Actinocamax-quadratus* Chalk at its outcrop at this point on the eastern side of Borough Hill.

(b) Exposure 300 yards east of Lower Farm.

At a point about 420 yards east-north-east of the phosphate-pit (**a**), and at a rather lower level, a rat-hole in a clover-field gave an indication of chalk near the surface. On deepening and enlarging the burrow, we encountered an obviously-phosphatic chalk in small angular blocks, so closely set as to leave no doubt that they belonged to the topmost layer of the rock *in situ*. Except that phosphatized

[1] 'The Zones of the White Chalk of the English Coast' Proc. Geol. Assoc. vol. xvi (1900) p. 333 & vol. xvii (1902) p. 26.

Textulariæ are rather more abundant, the wash-residues of this chalk exactly resemble those of bed (1) in the pit (**a**).

The unearthed blocks yielded remains of:—

Inoceramus.
Asteroid-ossicles.
Cidaris sceptrifera, Mant.
Cidaris sp.
Echinocorys sp.
Marsupites testudinarius, Schloth.
Porosphæra globularis, Phil.

As pieces of hard, greenish-yellow chalk and a few brown nodules occurred amongst the excavated material, we infer that the surface of the rock here nearly coincides with the junction of the beds numbered (1) and (2) in the pit (**a**). The south-westward dip in that pit would have led one to expect much older beds at this spot.

(**c**) Exposure near the south-eastern corner of Lower Farm.

This occurred, or, rather, was made, in the bottom of a plough-furrow nearly midway between exposures (**a**) and (**b**), about 10 feet lower than the latter. The chalk here is firm to rather soft, fine-grained, and white. Under the microscope, the coarse residues are seen to consist of subangular pieces of calcite, bits of flat shell (probably of *Ostrea*), Rotaline foraminifera, and prisms of *Inoceramus* (in relatively-small proportion), together with brown and amber-coloured chips of fish-bone, teeth, and scale, and an occasional pale-brown coprolite. The proportion of phosphatized material is so small, that the rock can scarcely be termed a Phosphatic Chalk.

The megascopic fossils noted are:—

Ostrea sp.
Rhynchonella plicatilis, Sow.
Asteroid-ossicles.
Uintacrinus.

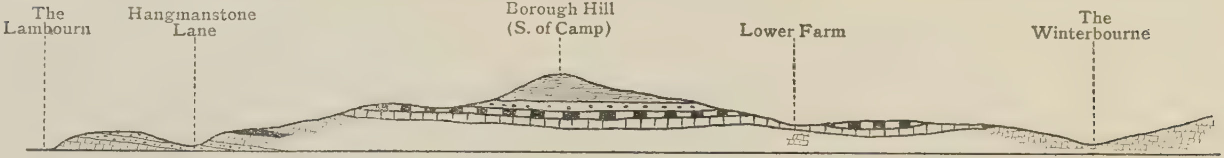
(**d**) Exposure 3 furlongs north-north-west of Lower Farm.

This is a patch of rubble, on the site of a ploughed-out pit in ordinary white chalk with seams of tabular flint. Fossils are few and unimportant. From the characters of the samples examined, and from evidence obtained farther west, we infer that the Chalk here belongs to the highest part of the *Micraster cor-anguinum*-Zone.

(**e**) Quarry 300 yards west of the New Inn, Winterbourne.

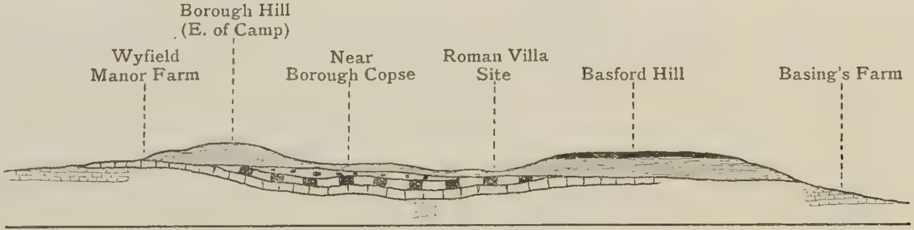
This is an abandoned working, in ordinary white chalk with bands of solid and hollow flint-nodules. Its nearer edge is a furlong distant from, and perhaps 20 to 25 feet lower than, the exposure lettered (**b**). The Chalk has yielded all the commoner fossils of the upper part of the *M. cor-anguinum*-Zone for this district, and not any that are distinctive of newer beds. The flint-bands are slightly

Fig. 3.—*Section along the line I–I on the sketch-map (fig. 1, p. 500). Base-line 300 feet above sea-level.*



Eocene (Reading) Beds. *quadratus*-chalk: phosphatic. *Marsupites*-chalk: phosphatic.
Uintacrinus-chalk: feebly phosphatic to normal. *cor-anguinum*-chalk: normal.
cor-anguinum-chalk: phosphatic. *cor-anguinum*-chalk: phosphatic.

Fig. 4.—*Section along the line II–II on the sketch-map (fig. 1, p. 500). Base-line 300 feet above sea-level.*



Eocene (Reading) Beds & Drift-Gravel. *quadratus*-chalk: phosphatic.
Marsupites-chalk: phosphatic. *Uintacrinus*-chalk: feebly phosphatic to normal.
cor-anguinum-chalk: normal.

[Scales, in both the above sections: horizontal, 1 inch =1760 feet; vertical, 1 inch =400 feet.]

waved, but have, on the whole, a gentle (apparent) dip towards the east-north-east.

Flinty chalk of the *Micraster cor-anguinum*-Zone is to be seen also in many small workings near the bottom and on the sides of the Winterbourne Valley, above and below the village, in some places close upon the boundaries of the Eocene Beds. These exposures it is unnecessary further to notice.

In the sloping ground on the eastern side of the Borough-Hill spur we have evidence, then, of the following downward succession:—

1. Reading Beds of the Borough-Hill outlier.		
2. Chalk with some flints, above pit (**a**).	Zone of *Actinocamax quadratus*.	
3. Phosphatic Chalk, in pit (**a**).		
4. Phosphatic Chalk { in pit (**a**) and exposure (**b**).	*Marsupites*-Band.	Zone of *Marsupites*.
5. Very feebly Phosphatic Chalk, in exp. (**c**).	*Uintacrinus*-Band.	
6. Chalk with tabular flints, in exposure (**d**).	Zone of *Micraster cor-anguinum*.	
7. Chalk with flints, in pit (**e**).		

The inconstancy of the dips in the Chalk makes it difficult to form just estimates of the thickness of the beds; but we think it unlikely that the upper and lower stratigraphical limits of the zone of *Marsupites* are much more than 30 feet apart in the immediate vicinity of Pit (**a**), a quarter of a mile north-west of Winterbourne Church. (See section, fig. 3, p. 510.)

III. Exposures in the Parish of Boxford.

Four out of the five Winterbourne exposures just dealt with fall within a narrow belt of country having an east-and-west trend. The more numerous exposures on the western, or Boxford, side of Borough Hill have, on the whole, a roughly north-and-south arrangement, and consequently furnish us with a fragmentary section at right angles to that given by the first series.

Beginning on the north, the first rubbly patch to be noticed is

(**f**) One furlong north-east of Wyfield-Manor Farm.

This is against the old hedge-bank which marks the Boxford-Winterbourne parish-boundary. The little chalk visible is soft, white, and fine-grained; it contains a few small fish-remains, but no phosphatized foraminifera. The only noteworthy organism represented in the samples taken was *Uintacrinus*.

(**g**) Pit 1 furlong west of Wyfield-Manor Farm.

This shows 8 feet of soft, white, blocky chalk, with a very few scattered nodules of flint near the top, and a thin seam of tabular

flint, which has an inclination of about 5° north-eastward—possibly an oblique vein. The chalk, which is non-phosphatic, resembles that of the upper part of the *Micraster cor-anguinum*-Zone in this district; and as the few fossils obtained during a close search include no forms suggestive of newer beds, we refer it to that zone. Though of little interest in itself, the pit acquires some importance from its proximity to the boundary of the Eocene Beds, which come on about 100 yards to the south-east, at a higher level by about 25 to 30 feet.

(**h**) Exposure 300 yards south-west of Wyfield-Manor Farm.

This is a broad patch of rubble, in clayey soil, about 160 yards south of, and 15 to 20 feet higher than, the pit (**g**), and close to the Eocene boundary, the position of which we could not determine within a few yards.

The chalk in the lower and western part of this scar is of the same character as that seen in the last pit, and with its surface-débris are associated many pieces of tabular flint. No distinctive fossils were forthcoming. The rubble in the higher part of the same patch, and the solid rock beneath it, however, have both yielded remains of *Uintacrinus*. The other fossils are

Inoceramus.	*Vincularia* sp.
Ostrea sp.	Asteroid-ossicles.
Rhynchonella plicatilis, Sow.	*Bourgueticrinus*.
Rhynchonella reedensis, Eth.	

It would seem that this patch of rubble marks the outcrop of beds immediately above and below the junction of the *Micraster cor-anguinum*- and *Marsupites*-Zones.

Some specimens of the *Uintacrinus*-Chalk contain a very small proportion of phosphatized material, in the form of coprolites and minute, subangular, brown objects (which may be concretions); others contain nothing of the sort. We have observed no phosphatized foraminifera.

Having regard to the character of the Chalk in the last three exposures, and to the position of the exposures themselves, it is highly probable that the Reading Beds in the northern part of the Borough-Hill outlier rest upon Chalk no younger than that of the *Uintacrinus*-Band. Setting aside all question of the thickness of the *Uintacrinus*-Chalk, there is clearly no room here for one quarter of the phosphatic beds of the *Marsupites*-Band and of later age seen on the eastern side of the outlier, near Winterbourne; and the only circumstance known to us which is in any way suggestive of the presence of some representative of that group near Wyfield Farm was the occurrence, on the surface, of a flint-cast of *Echinocorys scutatus* possessing the stunted pyramidate form characterizing the species in the highest *Marsupites*- and lower *quadratus*-beds in the pit (**a**). This cast was found, by one of us, a few yards to the east

of the rubble-patch (**h**). It has the greenish colouring and pitted surface of the flints in the Reading 'Bottom-Bed'; so that the possibility of its having been carried some distance from its parent-beds, in early Eocene times, must be added to that of its having been shifted by human agency after its appearance in the soil.

(**i**) Exposures by Rowhedge.

Along the northern side of the timbered cultivation-bank named Rowhedge, the Chalk, in many places, is so thinly covered by the soil, that one may obtain a fair idea of the changes in the larger lithological characters of its beds, from older to younger, while walking up the slope towards Borough Hill. Below the 400-foot contour-line the chalky soil is strewn with whole and broken flint-nodules. At or about that line the nodules are, to a large extent, replaced by fragments of tabular flint, which become scarcer higher up. From a trial-hole a little above the 400-foot line, and about 20 feet below the level of the base of the Reading Beds, we got samples of a soft, white, non-phosphatic chalk, with *Uintacrinus*. Ten feet higher (where the chalk is disappearing beneath a heavy wash of clay and pebbles) the same fossil and a stout example of *Porosphæra globularis* were found in white chalk, with small fish-remains and rare phosphatized foraminifera.

On comparing the positions of these exposures with those nearer Wyfield-Manor Farm, one gains the impression that the vertical distance between the base of the Eocene Beds, on the one hand, and the junction of the *Uintacrinus*-Chalk with that containing the tabular flints, on the other, is increasing towards the south; and the reality of this divergence is demonstrated a little farther on in that direction.

(**j** to **r**) Exposures near the Eocene boundary between Rowhedge and a point 150 yards south-east of Iremonger's Cottages.

(**j**)—At or close below the boundary of the Reading Beds, about 40 yards south of Rowhedge, there appear in the soil a few rough pieces of hard, yellow, distinctly Phosphatic Chalk, containing occasional green and brown concretions and impressions of sponges (mostly *Coscinopora quincuncialis* and *Ventriculites radiatus*). With these pieces of rocky chalk are associated guards of *Actinocamax*, some of which are sufficiently well-preserved to be safely referable to *A. granulatus*. Here we have found, also, part of a dwarfed pyramidate *Echinocorys scutatus*, with a valve of *Plicatula sigillina* attached, and a flint-cast of *Micraster cor-anguinum*, var. *latior*. Farther south, the bits of hard chalk become abundant and the belemnoids common, while the strip of ground on which they occur widens and assumes a gentler transverse slope. A trial-hole, made in a plough-furrow within this belt, proved a mass of hard rubble less than 2 feet below the

general surface of the field. It is to be inferred that this belemnoid-bearing rubble marks the outcrop of Chalk contemporaneous (if not continuous) with that forming bed (4) and the lower part of bed (5) of the Winterbourne (**a**) section, three-quarters of a mile to the east. We found remains of *Marsupites* and of *Uintacrinus*, in their proper relative positions, farther down the slope towards Hangman-stone Lane.

Followed southward, the upper limit of the rubble-belt diverges markedly from the Eocene boundary, and falls nearly to the 400-foot contour on the end of the blunt spur to the south-west of Borough-Hill Camp, leaving room for about 15 feet of higher Chalk between the rock-band which it indicates and the base of the Reading Beds. Near this spot, there seems to be a considerable development of hard beds in the Chalk, for a closely-packed rubble of the yellow, sponge-impressed rock, almost bare of soil, extends down the side of the valley (of Hangman-stone Lane) for a vertical distance of 40 or 50 feet, and is marked by a faint terrace-feature near its lower limit.

Between the end of the spur before mentioned and the head of the re-entrant by Borough Copse, the bed yielding the hard rubble either becomes greatly reduced in thickness, or is more thickly covered by wash from the Reading Beds, as it ceases to be continuously traceable. There are only two fair exposures of the *Actinocamax-quadratus* Chalk above it—those marked (**k**) and (**l**).

The first of these (**k**) is in a small overgrown pit, at the end of a cart-track. The southern side of the working shows a few square feet of soft, white, flintless chalk traversed by fine, straight, tubular borings filled with material of a coarse texture, in which fish-remains and brown grains are apparent. The wash-residues consist of unphosphatized tests of Rotaliidæ (to 0·7 mm. in diameter); plates and subangular lumps of calcite (commonly 0·2 to 0·5 mm.); prisms of *Inoceramus*; chips of fish-teeth, bones, and scales; a few brown coprolites and phosphatized casts of *Globigerina* and *Textularia*; some black granules and rare quartz-grains (to 0·25 millimetre).

The bigger fossils noticed in this slightly-phosphatized Chalk are:—

Inoceramus sp.
Ostrea sp.
Rhynchonella plicatilis, Sow.
Serpula plana, S. Woodw.
Asteroid-ossicles.
Porosphæra globularis (Phill.).
Porosphæra pileolus, Lam.

Part of what seems to be a detached body, or lenticle, of very hard yellowish chalk is exposed on the north side of the pit.

Exposure (**l**) is in a patch of soft rubble a little above the 400-foot contour, and close upon the boundary of the Reading Beds. The solid rock, forming a remarkably-even floor to the soil, and lying less than a foot below the surface, is coarse and gritty, and has the characteristic grey hue of Phosphatic Chalk. Its residues, which have a pink or flesh-coloured tint, resemble

those obtained from the upper part of bed (5) of the Winterbourne (**a**) section—small lumps and platy pieces of calcite and Rotaline foraminifera being the chief constituents. Phosphatized foraminifera (as usual, mainly *Globigerina* and *Textularia*), coprolites, fish-remains (which are responsible for the pink tinge), and black grains, all are common. When treated with hydrochloric acid, a small proportion of the phosphatized material (foraminifera, and grains or chips of uncertain origin) remains as pale-green translucent or opaque glauconite. Quartz-grains are very small, and rare.

The fossils collected include:—

Inoceramus sp.
Ostrea vesicularis, Lam.
Rhynchonella reedensis, Eth.
Clausa Francqana, d'Orb.
Vincularia sp.
Cythereis ornatissima (Reuss).
Cytherella ovata (Römer).
Cytherella Williamsoniana, Jones.
Cidaris sceptrifera, Mant.
Cidaris hirudo, Sorig.
Asteroidea.
Porosphæra globularis (Phill.).
Porosphæra patelliformis, Hinde.
Porosphæra sp.

Exposure (**m**).—At this place, on the northern slope of the little dale heading in Borough Copse, there is a broad spread of soft rubble, the chalk in and beneath which is distinctly phosphatic. A few broken guards of *Actinocamax granulatus (?)*, a stout *Porosphæra globularis*, and pieces of *Micraster* and *Echinocorys*, occur in the upper part of this patch, and plates of *Marsupites* in the lower—where there are clear indications of a thin band of hard, nodular rock similar to, and probably on the same horizon as, the bed numbered (2) in the Winterbourne (**a**) Pit.

At (**n**), in the bottom of the dale, about 150 yards south-south-east of this, and perhaps 20 feet lower, the plough has turned up soft, white, non-phosphatic chalk containing *Uintacrinus*.

From Borough Copse southward to the hedge west of the Roman Villa, there are frequent indications of a hard, yellowish chalk, with sponge-casts, a little below the 400-foot line, the plainest being at (**o**), where there is a small but distinct step or terrace in the slope, covered thickly by the débris of that rock. A little to the north-west of, and below this feature, gritty, phosphatic chalk, like that of the *Marsupites*-Band, occurs in the soil; and, still lower, the rubble of the *Uintacrinus*-Beds.

The same downward succession has been proved at the spot marked (**p**), and firm white chalk with tabular flints observed in the bottom of the dale, at 1 furlong to the north-west.

Between exposure (**p**) and Iremonger's Cottages, the Chalk is hidden by a 'creep' of pebbly clay; but at the latter place (**q**) soft though lumpy, white, non-phosphatic beds with thick bands or lenticles of very hard, yellowish-white, slightly-phosphatic rock containing green concretions and hollow casts of sponge-spicules, crop out in the cultivated ground immediately to the west, and, at a rather higher level, to the south, of the buildings. The wash-residues of the softer chalk here differ from those of all the chalks hitherto noticed, in consisting very largely of remains of bryozoa (notably *Crisina* and *Vincularia*), associated with those of *Pentacrinus*.

The fossils noticed are:—

Ostrea vesicularis, Lam.	*Membranipora* sp.
Kingena lima (Defr.).	*Eschara Lamarcki*, Hag.
Rhynchonella sp.	*Vincularia* cf. *longicella*. d'Orb.
Terebratulina striata (Wahl.).	*Bairdia subdeltoidea* (Münst.).
Clausa Francqana, d'Orb.	*Cytherella ovata* (Römer).
Crisina cenomana, d'Orb.	*Cidaris serrifera*, Forbes.
Crisina unipora, d'Orb.	*Cidaris* sp.
Entalophora virgula (Hag.).	*Metopaster Parkinsoni* (Forbes).
Entalophora Pergensi, Gregory.	*Bourgueticrinus*.
Tervia Gamblei, Gregory.	*Pentacrinus*.
Tervia subgracilis (d'Orb.).	*Porosphæra globularis* (Phill.).
Biflustra variabilis, d'Orb.	*Porosphæra* sp.

We are uncertain as to the age of these beds, as the above list of fossils from them contains nothing zonally distinctive. It might be supposed that the hard bands noticed here are the equivalent of those observed at and near the base of the *Actinocamax-quadratus* Zone, and in a similar position with reference to the base of the Eocene Beds, farther north; but this idea seems to be negatived by the evidence obtained a short distance to the south-east.[1]

The only other beds in this district in which we have found remains of *Pentacrinus* and an abundance of bryozoa are of *Micraster cor-anguinum*-age. These are described below [Pit (**u**), p. 517].

At the point lettered (**r**), about 150 yards south-east of Iremonger's Cottages, there is a surface-exposure of soft white chalk (the débris of which is mixed with very numerous green-coated flint-nodules and small green flint-pebbles), at the boundary of the Reading Beds. This contains small fish-remains and a few brown coprolites, and has yielded the following larger fossils:—

Ostrea vesicularis (?) Lam.	*Uintacrinus*.
Eschara Lamarcki, Hag.	*Porosphæra patelliformis*, Hinde.

Here then, at a distance of a little more than two-thirds of a mile south of Rowhedge, we again find the *Uintacrinus*-Beds in contact with the Reading Series, the higher Chalks, intercalated between them in the interval, having disappeared.

Still farther south, the *Uintacrinus*-Chalk itself is cut out, or very nearly so; for small pits at Broomclose Border, south-east of Basing's Farm, and little below the basal plain of the Eocenes, show normal flinty chalk of '*cor-anguinum*' aspect. (See section, fig. 4, p. 510.)

(s) Pit 1 furlong east of Boxford Rectory.

This is a little working showing a few feet of soft white chalk,

[1] [When the Geologists' Association visited the district shortly after the reading of this paper, Mr. A. C. Young found a well-granulated guard of *Actinocamax granulatus* in one of the surface-blocks of hard chalk a little to the west of the cottages. It is probable, therefore, that part, at least, of the rocky beds here belong to the zone of *A. quadratus*, and that the local succession is the same as that at the places marked (**m**), (**n**), (**o**), & (**p**).]

with small and widely-scattered flint-nodules. Fish-remains and a few coprolites occur in the residues. The Chalk contains very few fossils of megascopic dimensions, and proof of its *Uintacrinus*-age was obtained with difficulty. We could find no exposures of the Chalk (at least 30 feet thick), which comes in between the top of the pit and the base of the Reading Beds in Hoar (or Hour) Hill, to the south.

(t) Exposures in the banks of a lane south-east of Boxford Schools.

About 60 yards north-west of the pit (s), and 10 to 15 feet below the level of its floor, soft white *Uintacrinus*-Chalk occurs in the road-banks.

Nearer the Schools, at a lower level by about 30 feet, a very hard chalk, continuous with that seen at the top of the excavation now to be described, is exposed in a like position.

(u) Quarry 300 yards north-north-east of Boxford Church.

This is an old excavation of considerable size, but the greater part of its face is buried under bush-grown talus. The following succession can be made out near the northern end (descending order):—

	Feet
4. Soft to very hard, yellowish-white chalk, having a lumpy or nodular appearance on weathered surfaces, and containing a few flints in the lower part. The softer portions have an indistinctly-conglomeratic or brecciate structure. The harder occur in ill-defined bands parallel to the bedding, and in elongate bodies or pockets, at various angles thereto. Oysters abound in places, and are often so disposed in the mixed, hard and soft, lumpy chalk as to suggest that they grew upon very uneven fissured surfaces. The softer chalk of this bed, or group of beds, is distinctly phosphatic, the residues being rich in brown polished coprolites, casts of *Globigerina* and *Textularia* and other foraminifera, and a variety of organic débris of doubtful origin. Brown and light-green concretions of angular form (up to a quarter of an inch in diameter) are very abundant in places. Fish-remains occur, but are not very prominent .... about	10
3. Firm, harsh, irregularly-jointed, and lumpy, white chalk with one distinct band of nodular, and a few seams of tabular, flint near the middle. The residues of this chalk are bulky and often very coarse. Samples from the lower part of the bed are full of Asteroid-ossicles, fragments of *Inoceramus*, broken *Cidaris*-plates, etc. No phosphatic material was noticed. A thin seam of grey rubbly marl occurs at the base .... about	14
2. Yellow rocky chalk; minutely banded with iron-stains, and containing green concretions. The top of this hard band is even and clearly defined, and bears in places a very thin brown glaze. From it descend borings filled either with the marl or with soft chalk, the latter containing a small proportion of phosphatized material of the usual kinds	1 to 2½
1. Soft, white, blocky chalk, passing up into the above rock. It contains one prominent band of large flint-nodules (about 5 feet down) and many small, scattered, finger-shaped flints. Many of the big flints are studded with Asteroid-ossicles and remains of *Cidaris* and *Inoceramus*	7

The flint-band in bed (1), and the top of the hard chalk-band (2), dip about south-south-east at 23° to 25°. The higher beds are poorly exposed on a broken face, at a wide angle to the dip.

The names of the fossils obtained from the several beds are tabulated below:—

×= observed occurrence; c=common; vc=very common. BEDS...	1.	2.	3.	4.
Lamna appendiculata, Ag.	...	...	×	×
Exogyra sigmoidea, Reuss [1]	...	...	...	×
Inoceramus Cuvieri, Sow.	c	...	vc	c
Ostrea hippopodium, Nilss.	...	...	...	vc
Ostrea (cf.) *lateralis* var. *striata*, Nilss.	...	...	...	×
Pecten cretosus, Defr.	...	...	×	×
Teredo amphisbæna, Sow.	...	×	...	×
Kingena lima (Defr.)	×	...	...	×
Terebratula carnea, Sow.	...	×		
Terebratulina striata (Wahl.)	...	...	...	c
Berenicea polystoma (Römer)	...	...	...	×
Crisina cenomana, d'Orb.	...	...	...	×
Idmonea alipes, Gregory	...	...	...	×
Proboscina angustata, d'Orb.	...	...	...	×
Stomatopora gracilis (M.-Edw.)	...	...	...	×
Stomatopora granulata (M.-Edw.)	...	...	...	×
Tervia subgracilis (d'Orb.)	...	...	...	×
Membranipora sp.	×	...	...	×
Vincularia sp.	...	...	...	×
Bairdia subdeltoidea (Münster)	...	...	...	×
Cytherella ovata (Römer)	...	...	×	×
Serpula granulata, Sow.	...	...	...	×
Serpula plana, S. Woodw.	×	...	...	×
Cidaris clavigera, König	c			
Cidaris hirudo, Sorig.	×	...	×	×
Cidaris perornata, Forbes	...	...	...	×
Cidaris sceptrifera, Mant.	×	...	×	×
Echinocorys scutatus, Leske. Ovate form	...	...	×	
Helicodiadema fragile (Wilt.)	...	...	...	c
Micraster cor-anguinum (Klein)	×	...	×	×
Asteroidea	c	...	vc	
Bourgueticrinus	×	...	...	×
Pentacrinus	...	...	...	×
Porosphæra globularis (Phill.)	×	...	×	×
Porosphæra patelliformis, Hinde	...	...	...	×
Plinthosella squamosa, Zittel	×			

The Chalk seen in this quarry all belongs to the zone of *Micraster cor-anguinum*; and—to judge from the relative frequency of the species in the lowest bed, where the lithological conditions are normal—to horizons which are between 30 and 60 feet below the top of that zone in other parts of Berkshire.

That its strong dip towards the south-south-east is not maintained far behind the strike-face of the quarry, is evident from the

[1] So far as we can ascertain, *Exogyra sigmoidea* has not hitherto been recorded from the Chalk of this country.

presence of Chalk no younger than that of the *Uintacrinus*-Band at (**s**), a third of a mile distant in that direction, and some 40 feet higher, above sea-level. Unless there is a fault or sharp syncline between the two places, the beds must become horizontal, or nearly so, immediately to the south-south-east of the quarry. The fact that hard chalk, similar to, and, in part, clearly continuous with, that at the top of this working (**u**), is traceable in the rubbly soil southward to the lane by the School (**t**), favours the idea of a rapid flattening of the dip south-south-eastwards. There is evidence that the inclination of the beds decreases more slowly in the opposite direction. [See note on the pit (**w**), below.] We strongly suspect that it is a strikeward extension of this flexure which brings in the 'belemnoid-beds' on the south side of Rowhedge, at (**j**).

North-east of this quarry (**u**), hard chalk forms a marked bluff which follows the east side of Hangman-stone Lane to a little beyond the sharp bend near the figures '310' (see map, fig. 1, p. 500), and a belt of hard rubble extends from this bluff, east-north-eastwards, along the hedge towards the spread of similar débris, with *Actinocamax granulatus*, descending from near (**j**) and (**k**).

(**v**) Exposures about a third of a mile north-north-east of Boxford Church.

The arable land on the end of the rather acute and steep-sided spur in the angle between the Lambourn and Hangman-stone Lane valleys is thickly strewn with lumps of chalk and stout flint-nodules, evidently derived from the rock below. Samples of the solid chalk extracted on the lower and middle slopes of the spur, north-west of the angle in the road near the quarry (**u**), were found to be rich in phosphatized organisms: the bulky wash-residues containing an abundance of pale-brown casts of foraminifera, with the usual coprolites, fish-remains, and small concretions. Most of the unphosphatized material is comminuted *Inoceramus*-shell. Megascopic fragments of *Micraster* and *Inoceramus* are very common, and the greater part of two tests of *M. cor-anguinum* were found in the rubble on the surface.

The chalk on and below the surface at the top of the spur contains (at the points where samples were taken) a very small proportion of phosphatic granules, and is evidently very flinty.

The high south-south-eastward dip noted in the quarry (**u**) about 1 furlong to the south, as also the absence of the hard beds there found, leads us to infer that the Phosphatic Chalk on the middle and lower slope at the end of this spur is older than any hitherto dealt with in this paper. Its thickness is unknown, since the dip could not be ascertained. Its position with reference to the next pit (**w**), and the characters of the associated Micrasters, enable us to assign it to the upper half of the *Micraster cor-anguinum*-Zone.

(w) Pit at Westbrook Farm.

This is in normal Chalk, rich in flints but very poor in fossils, and having the appearance of that particularly-uninteresting rock which is usually found in the midst of the *Micraster cor-anguinum*-Zone in this district. The pit is mentioned, because it shows the beds at that spot to be dipping in the same direction as those in the Boxford Quarry (**u**), a third of a mile to the south-east, but at an angle of only 5° or 6°.

The descending succession recognized on the western, or Boxford, side of the Borough-Hill ridge is, then, as follows:—

1. Reading Beds of the Borough-Hill Outlier.		
2. Phosphatic Chalk; exposures **k, l, j, o, p, q**?	Zone of *Act. quadratus.*	
3. Phosphatic Chalk; exposures **m, o, p**	*Marsupites*-Band.	Zone of *Marsupites.*
4. Feebly-phosphatic to normal Chalk, with few flints; exposures **f, h, i, n, o, p, r, s, t** ...	*Uintacrinus*-Band.	
5. Normal flinty Chalk; exposures **g, h, i**	Zone of *Micraster cor-anguinum.*	
6. Phosphatic Chalk; pit **u**		
7. Normal flinty Chalk; pit **u**		
8. Phosphatic Chalk (? with flints); exposure **v**		
9. Normal flinty Chalk; pit **w**		

The maximum thickness of the Phosphatic Series, from the base of the beds numbered (8) to the summit of those numbered (2), in the above succession, we roughly estimate at 130 feet; assigning to the

	Feet.
Actinocamax-quadratus Beds.....................	20
to the *Marsupites*-Zone	30 to 40
and to the *Micraster cor-anguinum*-Beds......	80 to 70

IV. Concluding Remarks.

The data collected in the piece of country dealt with in this paper suffice to show that the more or less Phosphatic Chalks above the *Uintacrinus*-Band between the villages of Winterbourne and Boxford lie in a trough or basin the formation of which antedates the deposition of the Reading Beds (see fig. 4, p. 510). When the area of observation is extended, it is found that the *Uintacrinus*-Chalk of that tract itself lies in a structural depression.

In view of the development of phosphatic and of hard rocky beds, indicative of slow and interrupted sedimentation, in the underlying *cor-anguinum*-Zone, it seems not unlikely that this basin is an original, or inherent, feature of the Chalk, directly attributable to a local attenuation of that zone. That this explanation contains some elements of truth we do not doubt, but the unusually pronounced dips noticeable in the larger excavations in the district, and, above all, the remarkable disturbance which has tilted the Chalk near Boxford at an angle of 25°, strongly suggest that the troughing which sheltered the outlier of phosphatic and normal

beds of *Marsupites*- and later age from the early Eocene planation is due, in no small degree, to differential earth-movements taking place either soon after or during the formation of the Chalk. We hope to enter more fully into this question on another occasion. It may, however, be mentioned that this is the third locality within the area of the London Basin where we have noticed the incoming of higher beds of the Upper Chalk, as outliers, beneath the Eocene strata to be heralded or accompanied by a marked increase in the inclination of the bedding-planes of the former rock.

The Winterbourne-Boxford phosphates have a known range in time considerably greater than those of Taplow. Their advent far down in the *Micraster cor-anguinum*-Zone is especially interesting, for in England, as Mr. Jukes-Browne has remarked, that subdivision of the Chalk almost everywhere

'presents the appearance of having been quietly and continuously accumulated in water that was seldom disturbed by bottom-currents'[1];

albeit a tendency to develop hard bands at one horizon, at least, is apparent in the western part of the London Basin.

It is difficult to find a satisfactory explanation of the persistence, or frequent recurrence, of the exceptional conditions responsible for the formation of such deposits, at one spot on the floor of the Senonian Sea, throughout an epoch which seems to have been no inconsiderable fraction of Cretaceous time.

The Phosphatic Chalks of Winterbourne and Taplow evidently mark places on the sea-bottom particularly liable to the impingement of strong currents, and may mark places above which the water commonly had a gyratory motion, as in an eddy. In any case, their zonal range argues a marked degree of stability in the current-system of the body of water in which they were laid down.

In concluding, we desire to express our thanks to Mr. George Baylis, who has kindly given us access to his land around Wyfield Manor; and also to the Misses Baylis, to Messrs. Frank Comyns, M.A., H. A. Allen, W. D. Lang, M.A., R. Bullen Newton, and Herbert L. Hawkins, who have assisted us in various ways.

Discussion.

Mr. Strahan congratulated the Authors upon their discovery of another occurrence of Phosphatic Chalk, and expressed his high appreciation of the precise zonal work which they had carried out in their investigation of the deposit. The results that they had obtained could have been got in no other way. They had proved that the phosphatic deposits had a greater vertical range than at Taplow; they had confirmed their conclusion that the phosphatization accompanied an abnormal condition of some of the zones; and they had proved the existence of pre-Eocene flexures in the Chalk

[1] Mem. Geol. Surv. 'The Cretaceous Rocks of Britain' vol. iii (1904) p. 368.

in both localities. It was noteworthy that the character of the phosphates suggested a place where small fishes had thriven and fed, rather than one where they had died. The deposit differed from most fish-beds, in the fact that coprolites were numerous out of all proportion to bones. It was still a question what the fishes were, and where they left their bones.

Mr. TREACHER, having thanked the Chairman (Dr. J. E. Marr) and the Fellows for their kind reception of the paper, said that the failure of Mr. Strahan to find this particular deposit during his search for Phosphatic Chalk some years ago, after his discovery at Taplow, might be explained by the fact that the exposure at Winterbourne was a very small one in the middle of a field, out of the way of any public road, and that much of the evidence given in the paper was obtained by the Authors by making small excavations in the ploughed fields for the purpose. As was mentioned in the paper, the first discovery of the belemnites and other fossils was due to the interest taken in geology by members of the family of Mr. George Baylis, of Wyfield Manor, on whose land nearly the whole of the chalk dealt with is situated. This is a good instance of the useful work which local geologists may do, even if only beginners in the science.

With reference to Mr. Strahan's remark as to the abundance of coprolites of small fishes found in the Phosphatic Chalk and the comparative scarcity of their bones, it might be observed that many minute chips of bone did occur, and that much of the material might have been dissolved and the phosphate therefrom taken up by foraminifera, shells of molluscs, and other organic remains, which were found in a more or less phosphatized condition. The swarms of belemnites might also have had something to do with it.

Mr. H. J. OSBORNE WHITE remarked that there was still much to be learned about the structure of those parts of the country that were occupied by the Chalk. The preparation of a zonal map of the formation was much to be desired. He joined Mr. Treacher in thanking the Fellows for the reception accorded to the paper.

24. *On the* Occurrence *of* Limestone *of the* Lower Carboniferous Series *in the* Cannock-Chase Portion *of the* South Staffordshire Coalfield. By George Marmaduke Cockin, F.G.S. (Read March 7th, 1906.)

The South Staffordshire Coalfield embraces a district 26 miles in length, and includes the southern portion of Staffordshire as well as portions of Worcestershire, Warwickshire, and Shropshire. Over the southern portion of this coalfield the Coal-Measures rest directly upon the Silurian limestone. This is known to be the case as far north as the Great Bentley Fault, north of which a deep sinking and borehole at No. 2 pit, Cannock-Chase Colliery, proved a thickness of 1212 feet of Coal-Measures below the Deep Coal-Seam, succeeded by 102 feet of limestone-rock, said to be Silurian limestone.

It has been thought up to the present time, in the absence of any proof to the contrary, that the Lower Carboniferous rocks are altogether wanting in this area. Jukes, in his Geological Survey Memoir on the South Staffordshire Coalfield, 2nd ed. (1859) p. xii, says:—

'These vast formations of Old Red Sandstone and Carboniferous Limestone (to say nothing of the lower part of the Coal-Measure Series or Millstone Grit) are altogether absent in South Staffordshire, neither is there the slightest reason for supposing that any part of them ever existed in that district.'

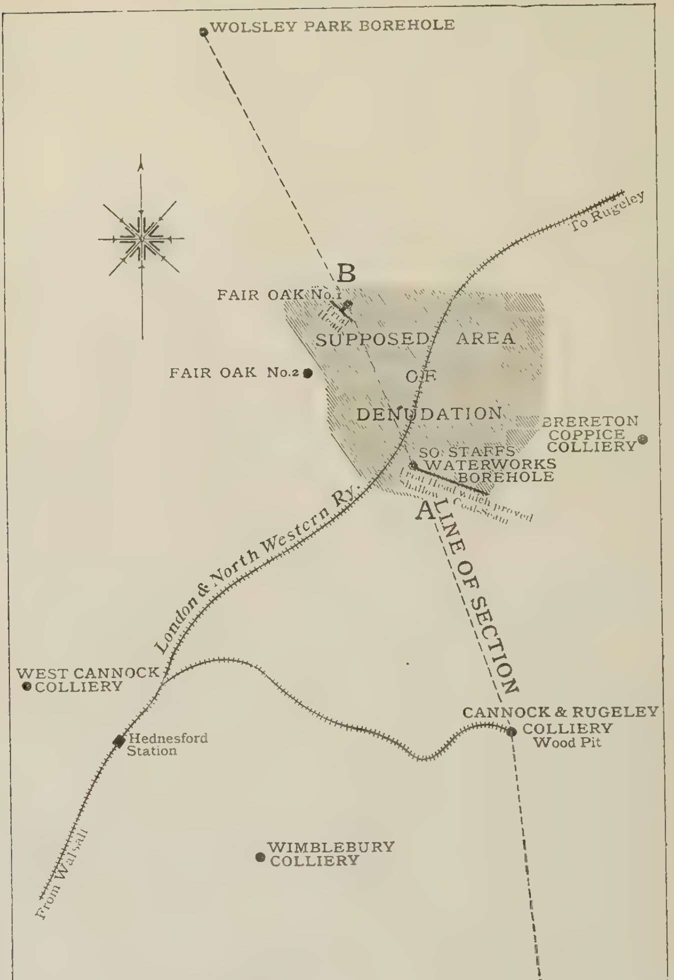
Dr. Charles Lapworth & Mr. A. Sopwith, in Part III of the Report of the Royal Commission on Coal-Supplies, published in 1905, make the following statement:—

'Neither Carboniferous Limestone nor Millstone Grit are known to occur within the limits of the South Staffordshire Coalfield. The oldest beds yet recognized are certain Ganister-like strata associated with the deepest Coal-Measures in the borings in Cannock Chase. In the neighbourhood of Walsall and Dudley the basement Coal-Measures lie at once unconformably upon the Silurian rocks; and this also appears to be the case somewhat farther north, as shown in the boring at No. 2 Pit, Cannock-Chase Colliery. Elsewhere in the Cannock-Chase area proper, the base of the South Staffordshire Coal-Measures has not yet been proved.'

Over 30 years ago a shaft was sunk at No. 1 Fair Oak, about 5 miles north of the boring at No. 2 Pit, Cannock-Chase Colliery. No workable seam of coal was found at No. 1 Fair Oak in the 975 feet of strata sunk and bored through. The coal found consisted of a seam 3 inches thick at a depth of 420 feet, and another half an inch thick at a depth of 567 feet.

The failure to find the workable seams of the district may be attributed to the fact that the Coal-Measures at and above the horizon of the Deep Coal-Seam have been denuded over an area shown by shaded lines in fig. 1 (p. 524). Afterwards a pair of shafts, called No. 2 Fair Oak, were sunk 800 yards distant, and excellent coal of normal thickness was there found, and worked to a considerable extent. The shaft at No. 1 Pit was 15 feet in diameter, and was

Fig. 1.



PLAN

Shewing line of Section over a portion of the

CANNOCK-CHASE COALFIELD.

The Area of Denudation shaded thus

Scale,-1 inch=1 mile.

sunk to a depth of 249 yards, the remainder being bored: a descriptive section of the strata passed through is appended below. Before the undertaking was abandoned, an exploration-head was driven in the dark shales at the bottom of the shaft to the full dip of the measures—30° or 1 in 1·75—for 44 yards, and from it heads were driven at right angles for 150 yards on the strike.

Account of Strata sunk and bored through at No. 1 Pit, Fair-Oak Colliery. Completed October 25th, 1875.

Description of Strata.	*Thickness.*			*Total thickness.*		
	yds.	ft.	in.	yds.	ft.	in.
Gravel and sand	4	1	11	4	1	11
Bunter sandstones and conglomerates, containing copper-pyrites and galena in places	90	2	8	95	1	7
Red marls, with large ironstone-nodules, and light-grey sandstones	45	1	2	140	2	9
Smutty coal			3	141	0	0
Red marl	2	0	3	143	0	3
Red and white sandstones and shales	12	1	7	155	1	10
Purple marl	6	0	0	161	1	10
Red shale	4	2	6	166	1	4
Black shale, with numerous fossil shells	1	0	9	167	2	1
Carbonaceous shale and smut			9	167	2	10
Grey clay	6	0	6	174	0	4
Dark shales, with ironstone-bands and nodules	15	0	6	189	0	10
Coal			½	189	0	10½
Hard coarse sandstones	9	2	8	199	0	6½
Shales, with ironstone-balls	18	1	8	217	2	2½
Fireclay		2	2	218	1	4½
Hard grit	3	0	0	221	1	4½
Dark tough clay		2	3	222	0	7½
Shales and ironstone	11	0	0	233	0	7½
Peldon [a very hard, flinty stone]	1	0	4	234	0	11½
Carbonaceous shale and clay			9	234	1	8½
Strong fireclay	2	1	0	236	2	8½
Blue shale	1	0	0	237	2	8½
Dark shale (exploring heads are in this)	9	2	0	247	1	8½
Hard grit (bottom of shaft)	1	2	0	249	0	8½
Dark shale (bore-hole commences)	3	1	3	252	1	11½
Hard grey jointy grit	1	1	6	254	0	5½
Shales and ironstone	1	2	6	255	2	11½
Dark peldon		1	6	256	1	5½
Shales and ironstone-bands	23	2	5	280	0	10½
Red sandstone		1	6	280	2	4½
Dark shales	9	2	0	290	1	4½
Red and variegated sandstones and shales	19	0	7	309	1	11½
Hard brown sandstone, with salt water	10	0	0	319	1	11½
Hard red sandstone	2	2	7	322	1	6½
Red sandstone, with marl-partings and water	2	2	0	325	0	6½

The waste-heaps had remained undisturbed since 1875, until three or four years ago, when Mr. George Wetherall of Rugeley,

then a Clifton boy of thirteen—a nephew of Prof. Bonney—drew my attention to some fossils that he had found there. He had already shown them to Prof. Bonney, who had explained to him the anomaly and also the importance of placing the matter beyond doubt: the credit of the discovery is entirely due to Mr. Wetherall.

Subsequent search has led to the discovery of a quantity of fossils belonging to the Lower Carboniferous Limestone. The fossils occur in a dark shaly limestone or in a calcareous grit, occasionally stained red. Some are weathered from long exposure on the heap. In no case has the limestone any appearance of being water-worn, but is in the condition in which it would be after being blasted out *in situ*. The fossils have been submitted to and named by Dr. Wheelton Hind, F.R.C.S., F.G.S., and are as follows:—

Brachiopoda.

Athyris planosulcata, Phil.
Chonetes laguessiana, de Kon.
Orthothetes crenistria, Phil.
Productus giganteus, Martin.
Productus longispinus, Sow.
Productus punctatus, Martin.
Productus semireticulatus, Martin.
Rhipidomella Michelini, Léveillé.
Seminula ambigua, Sow.
Spirifer planicostatus, M'Coy.
Spiriferina cristata, Schlotheim.

Cephalopoda—a fragment.

Corals.

Amplexizaphrentis, Vaughan, MS.
Millepora rhombifera, Phil.

Crinoidea—Stem-joints.

Gasteropoda—*Platyschisma* (?).

Echinoidea—*Archæocidaris Urei* (?) Fleming (plates).

Lamellibranchiata—*Parallelodon* sp.

Fish-remains—Scales and teeth.

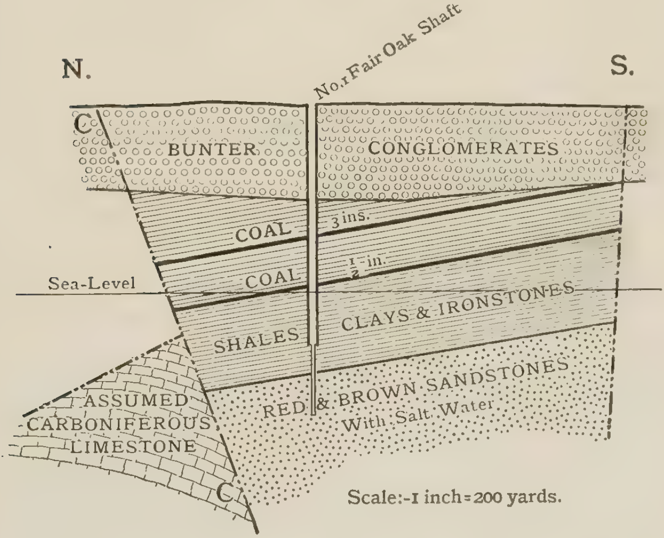
The position of Fair Oak with respect to the Cannock-Chase portion of the South Staffordshire Coalfield is shown on the plan (fig. 1, p. 524); one of the most important features there represented is the supposed area of denudation of all the workable seams, indicated by the shaded portion. The area has been proved, to a certain extent, by mining operations; the denuded portion has been largely replaced by Bunter Conglomerates.

Fig. 2 (p. 527) shows the position of the Lower Carboniferous rocks, so far as can be ascertained at No. 1 Fair Oak. This (as already stated) is about 5 miles north of the deep sinking and bore-hole at No. 2 Cannock-Chase Colliery. The Bunter Conglomerates overlying the Coal-Measures thicken gradually northward, until they attain their maximum thickness of 300 feet at Fair Oak. About 1 mile south-east of Fair Oak a trial-shaft and heading at the South Staffordshire Waterworks encountered what was believed to be the Shallow Coal, cropping up into the Gravel-Beds; it is probable that this marks the edge of the denudation referred to: further confirmation of this is required, and it is hoped that future mining operations will settle the point and prove the actual extent of the denudation. It will be understood that the fault shown at C in fig. 2 is hypothetical, and is only introduced as affording one explanation of the existence of Carboniferous Limestone at that locality.

There can be no doubt whatever that the limestone was met with in one of the exploring-heads immediately before the abandonment of the undertaking. Either the lower beds of the Coal-Measures thin rapidly to the north, or else a rise-fault was met with as shown. The position occupied by the limestone on the waste-heap points to its having been the last material deposited there.

About $1\frac{1}{2}$ miles north-west of Fair Oak, in Wolsley Park, a bore-hole has lately been put down to prove the Coal-Measures. The

Fig. 2.—(*See p. 526.*)



depth bored was about 396 yards; and Mr. Walcot Gibson, in the Transactions of the North Staffordshire Field-Club, 1903-1904,[1] expresses the opinion that the strata below a coal-seam at 257 yds. 2 ft. 6 in. suggest that the boring passed through the Lower Coal-Measures and ended in Millstone Grit.

These evidences of Carboniferous Limestone and Millstone Grit are the first that have been brought forward to prove the existence of the Lower Carboniferous rocks under the Cannock-Chase portion of the South Staffordshire Coalfield.

Discussion.

Prof. Bonney said that, as he had known this part of Cannock Chase before the Fair-Oak pit was sunk, and had been aware of the discovery of Carboniferous marine fossils before it was communicated to the Author, he would add a few words. Some four years ago his

[1] 'Sections of Boreholes & Wells in the County of Stafford' p. 123.

nephew, George Wetherall (then about thirteen), showed him some fossils which he had picked up on the spoilbank. They were joints of crinoid-stems and one or two species of *Productus*. He told the lad that they were likely to be Carboniferous Limestone, but explained to him why its occurrence was improbable, and urged him to go on searching, when home for the holidays. He collected more: they were submitted to Mr. E. T. Newton, who kindly identified them; and the speaker was intending to publish a short note in the discoverer's name, when he heard that the latter had told the Author, who was at work on a paper. So, as he was so much better acquainted with the details of the Coalfield, the speaker left the subject to him; and the result was the interesting communication to which they had listened. The reason for being so cautious was this: about 22 miles to the east, the Carboniferous Limestone appeared to thin out on the north side of Charnwood Forest; it was doing the same near Wellington, about 47 miles to the west; it was probably wanting under the Leicestershire Coalfield, and certainly under the Warwickshire, Forest-of-Wyre, and Shropshire Coalfields,—in other words, over a semi-circular district of which Fair Oak was the centre. He thought that the discovery marked a point in the southern shore-line of the northern sea-basin, perhaps a bay: thus resembling the limestone on the Titterstone-Clee Hills, which must occupy a similar position on the northern shore-line of the southern basin.

Mr. J. T. Stobbs, who was unable to be present, sent the following contribution to the discussion:—

'It is absolutely certain that the débris has been raised out of the shaft: whether it was met with in the shaft itself, or in the heading, is not of general importance. The horizon of the deposit may be referred to one of those limestones that occur near the base of the Pendleside Series, or the uppermost part of the Carboniferous Limestone; and the Author is to be congratulated on the paper, which is an important contribution to the problem of the continuation of the overlain coalfields of Mid-Staffordshire. The existence in this locality of a ridge of Carboniferous rocks belonging to a much lower horizon than the lowest workable coal-seams occurring in the Midland Counties is beyond dispute.

'Another question is raised by this discovery, namely: whether the limestone proved at the bottom of the borehole at No. 2 Cannock-Chase Colliery was Silurian or Carboniferous. So long as people were prepossessed with the idea, scattered broadcast in geological and mining literature, that the Coal-Measures of this Coalfield reposed unconformably on the Silurians, and that the Lower Carboniferous rocks were absent, it was natural that any limestone found at a great depth below the lowest coal-seam should be regarded as a Silurian limestone. It is now of importance to know whether the person who examined the cores was competent to determine Silurian, as distinguished from Carboniferous Limestone: in other words, can we be certain that this limestone was Silurian, and not Carboniferous?'

Dr. Wheelton Hind also sent the following contribution to the discussion:—

'The observations made by the Author are most important, and of great interest. They afford further evidence of the gradual attenuation of the whole of the Lower Carboniferous rocks as they pass south. Of course it has been long known that the Carboniferous Limestone is still present at Lilleshall and near Wellington, both about the same latitude as the Fair-Oak Colliery at

Cannock Chase. At the last-named a thickness of only a few feet represents the whole of the Carboniferous Limestone of the Midlands, and the fossils distinctly point to the fact that the fauna found by the Author represents the very highest beds of the Carboniferous Limestone of the Midlands. The coral-fauna (*Amplexizaphrentis*) is found in the upper part of the Upper *Dibunophyllum*-Zone of Vaughan. The presence of *Productus giganteus* with the corals makes the horizon absolutely definite. Attenuation of the Carboniferous Limestone to the south has therefore taken place at the expense of the lower beds, which gives important evidence as to the physiography of that period. Farther south the Coal-Measures rest directly upon Silurian rocks, the whole of the Lower Carboniferous Series being absent in South Staffordshire. I congratulate the Author on his valuable paper.'

Mr. Walcot Gibson referred to the occurrence of Carboniferous Limestone at Lilleshall and at the northern end of the Leicestershire Coalfield, and also in a boring at Kettering Road near Northampton. Over the Warwickshire and South-Staffordshire Coalfields its absence was well known. With reference to the presence of Carboniferous Limestone in the Fair-Oak trial-shafts, it was interesting to find that pebbles of Carboniferous Limestone are common in the conglomerates of the Upper Coal-Measures and so-called 'Lower Permian' of the Severn Valley; while they are rare or are absent from these conglomerates in Warwickshire. It is, therefore, certain that the Carboniferous Limestone was being denuded during the later stages of the Coal-Measure Period. The limestone at Fair Oak would furnish one probable source for the pebbles in the conglomerates of the Upper Coal-Measures of the Severn Valley.

Prof. Watts referred to the dolomitization of the Carboniferous Limestones north of Charnwood Forest; and asked whether the limestone of Fair Oak was in a dolomitic condition.

The Author remarked that but little reply seemed necessary. No samples of Silurian limestone had been left at Cannock-Chase Colliery No. 2, but there was very little doubt that such limestone had been found there.

25. *On a* Case *of* Unconformity *and* Thrust *in the* Coal-Measures *of* Northumberland.

By George Alexander Lebour, M.A., M.Sc., F.G.S., Professor of Geology in Armstrong College; and J. A. Smythe, M.Sc., Ph.D., Lecturer in Chemistry in Armstrong College, Newcastle-upon-Tyne. (Read April 4th, 1906.)

[Plate XLII—Section.]

I. Introduction.

The object of this paper is to describe a case of unconformity, accompanied by a certain amount of horizontal thrusting, which occurs in the Coal-Measures exposed—chiefly at low water—on the coast of Northumberland at the foot of the Whitley cliffs, and is traceable for upwards of a mile.

The section studied stretches from the bold headland formed by the Table Rocks,[1] northwards almost as far as the Brier-Dene Burn. At the southernmost end—that is, at the Table Rocks—the plane of erosion in question dips and disappears beneath the sea. Near the mouth of Brier Dene it is permanently covered and concealed by Drift and beach-deposits.

The Table Rocks consist of a series of ledges of sandstone, bedded almost horizontally, and presenting vertical cliff-faces to the sea. A little north of this the cliff becomes overhanging, owing to the undercutting by the waves of the soft beds which come to light at its base.

Near the spot marked M on the sketch-map (fig. 1, p. 532), the sandstone-cliff, which so far varies from 30 to 40 feet, gradually lessens in height, and is overlain by a considerable thickness of Boulder-Clay. Up to this point also the foreshore is free from cover, though strewn with boulders, and in places obscured by talus-heaps burying the cliff-foot, and the strata comprised in it can be well seen at low tide. Farther north, however, the boulder-strewn outcrops give place to a broad sandy beach (Whitley Sands proper), which is broken, near low-water-mark only, by a reef of sandstone. But, after specially-heavy storms, the shifting sands, at rare intervals of time, bring into view sometimes shingle, and sometimes solid rock. It was after such a storm that an unusually-fine exposure of the unconformity was observed and recorded by one of us more than twenty years ago.[2] It is only by watching the coast, and seizing favourable opportunities during many years, that most of the details here given have been obtained.

The uppermost deposit along this portion of the coast is the

[1] This name, although always used in the locality, has not, unfortunately, been adopted by the Ordnance Survey.

[2] See 'Nature' vol. xxv (1881) p. 79 (November 24th).

yellow sandstone which forms the Table Rocks, and we shall call it by that name. About 40 feet of this well-marked rock is visible in the cliffs of which it is the main constituent, and its total thickness, as shown in sinkings inland, is not more than 50 feet. It is more massive and compact in the southern parts of the section, thin and irregular subordinate layers of shale developing within it farther north. Its base lies unconformably upon a series of alternating shales and sandstones, and it is this unconformable junction which we propose to describe.

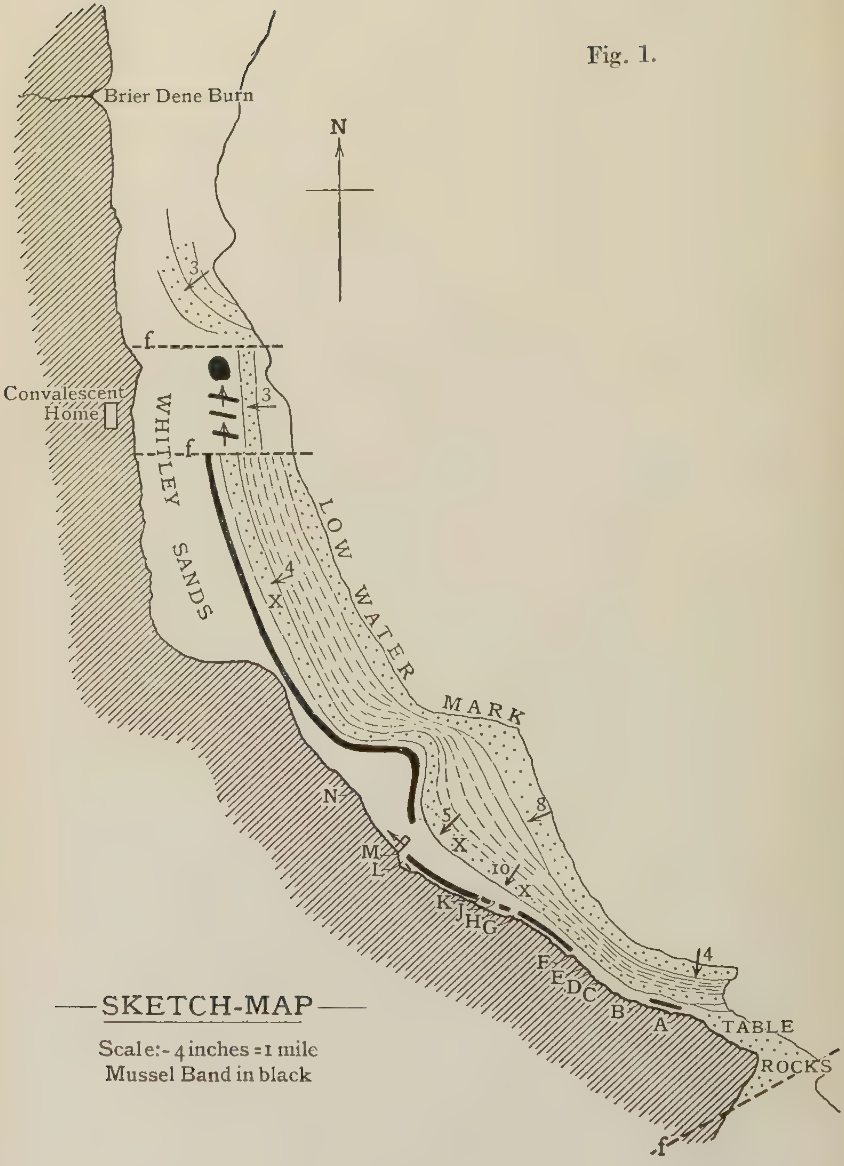
From beneath the line of unconformity to the lowest tide-level, about 30 to 40 feet of the shales and sandstones just mentioned can be observed and measured; but only the topmost 8 or 10 feet of this series can be proved to have been subjected to the denudation which preceded the deposition of the Table-Rocks Sandstone, although it is natural to suppose that considerably more was involved in an erosion so widespread as this. How much missing rock the unconformity may represent it is not possible, with the evidence at present available, to tell.

The dip of both sets of beds—above and below the unconformity—is, except where in the lower these are faulted and disturbed, one of a few degrees (about 4° on the whole) to the south-west, or inland. This brings about a general parallelism between the scarped outcrops of the cliff-making Table-Rocks Sandstone and the hard bands of sandstone of the lower series, which has, no doubt, helped for many years to mask, and withdraw attention from, the unconformity.

Since beds of shale and sandstone (such as those of the lower series) are of the kind which is common in all parts of the Coal-Measures in this coalfield, and bear no special characters by which they could be distinguished, it is fortunate that the series includes in its upper portion a stratum of marked individuality—a bed of clay-ironstone crowded with shells of *Carbonicola* (olim *Anthracosia*) *aquilina*, which we will call the Mussel-Band, a bed which serves as a most useful and unmistakable horizon of reference.

It may be permissible to remind the reader that in the Upper Carboniferous of the North of England, mussel-bands are, with the possible exception of the thicker coal-seams only, quite the most persistent strata met with. In consequence of their remarkable constancy, they are of great use as guiding-beds in seeking for, and in correlating, certain coals. If the correlation adopted in the Geological Survey-map of this district be followed, then this particular shelly ironstone is one well-known as occurring a little way above the Low Main Seam, but this reference we are not at present in a position either to combat or to confirm. Indeed, the recognition of the unconformity throws many difficulties in the way of the correct interpretation of inland pit- and bore-sections, and doubt must (for a time at least) exist as regards several of them.

Fig. 1.



SKETCH-MAP

Scale:- 4 inches = 1 mile
Mussel Band in black

The beds referred to in this paper are the following :—

UPPER SERIES.	Feet.
The 'Table-Rocks' Sandstone	30+
Unconformity.	
LOWER SERIES.	
Shales	12+
Mussel-Band ... about	1
Shale	3
Sandstone	8
Shale	8
Sandstone	10 to 12
Shales, etc.	—

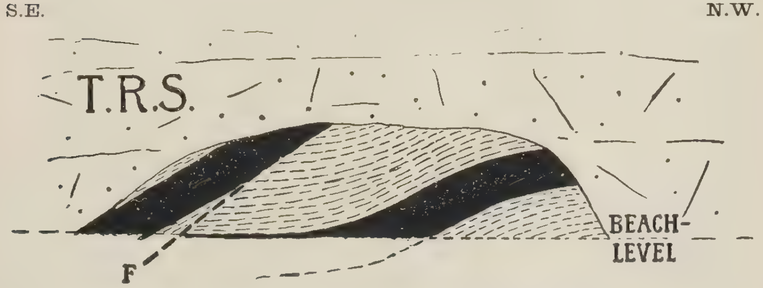
II. DESCRIPTION OF THE PHENOMENA.

We will now briefly describe the more noteworthy facts observable in following the unconformity from south to north, taking each point as it comes.

From A (see sketch-map, fig. 1, p. 532), where the junction of the two series emerges from the sea, to B, there is no discordance of dip, and no disturbance in either: nothing, in fact, to draw the attention to any break in the succession. A thin shale, merely, separates the Mussel-Band from the Table-Rocks Sandstone. The actual junction is buried under shore-deposits.

At B, the base of the Upper (Table-Rocks) Sandstone is suddenly raised to accommodate a small faulted and denuded portion of lower beds. This disturbed space, 6 to 7 feet in length, includes a high dip of the Mussel-Band and a reversed fault of small throw, hading to the south-east, as shown in fig. 2, below.

Fig. 2.—*Section B; length of section = 6 feet.*



[The vertical scale is the same as the horizontal.]

T.R.S. = Table-Rocks Sandstone; the Mussel-Band is shown in black.

A few yards farther on, the line of unconformity again rises above the beach-level, and another and longer islet of shale (beneath the horizon of the Mussel-Band) is well shown. The junction here is of especial interest, as the Table-Rocks Sandstone at its very base is

seen to contain pebbles of material belonging to the Lower Series. These pebbles will be referred to more fully, later. The shales beneath the unconformity are discordant as to dip from the sandstone above, but not otherwise disturbed or faulted.

For the next 40 yards the junction is again hidden beneath the boulder-covered beach, until at C another good exposure is obtained. Pebbles are once more present. The dips are very discordant, and towards its northern end the lower set of beds is disturbed by faults of great hade. (See fig. 3, below.)

Fig. 3.—*Photograph showing the fault in the Lower Series stopping short at the base of the Table-Rocks Sandstone.*

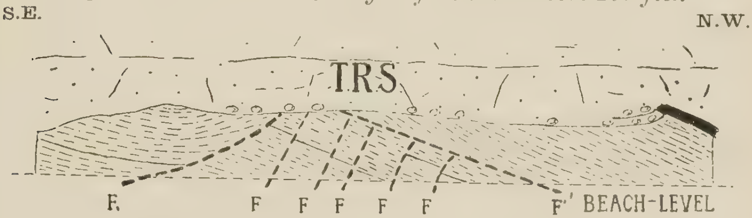
Some 25 to 30 yards of stony talus intervenes between this and the next fine exposure, from D to E. Here the discordance is very marked, the lower beds exhibiting synclinal and anticlinal folds, on the denuded edges of which the Table-Rocks Sandstone lies nearly flat, with some pebbles (not only, this time, at its immediate base, but, towards the northern end of the section, also a foot or two higher up). A notable feature here, is the way in which the central portion is shattered by a number of small faults, about half of which are reversed. All the smaller faults hade to the south, and are fractures subordinate to a larger fault hading to the north at an angle of about 45°. At E the bottom-layers of the Table-Rocks Sandstone are somewhat violently upturned, as if on meeting the resistance presented by the hard Mussel-Band, which here reappears abutting against the line of junction, and dipping at a fairly high angle to the north. (See figs. 4 & 5, p. 535.)

About 20 yards farther north, a perfectly-concordant junction is seen for a short distance, with horizontal shale beneath the equally-

horizontal Table-Rocks Sandstone, at the base of which pebbles again occur.

Another 25 yards of unseen talus-covered junction brings us to what is one of the most violently-disrupted episodes (F) in the

Fig. 4.—*Section D to E; length of section = about 100 feet.*



[The vertical scale is the same as the horizontal.]

Fig. 5.—*Photograph illustrating fig. 4. (See also p. 534.)*

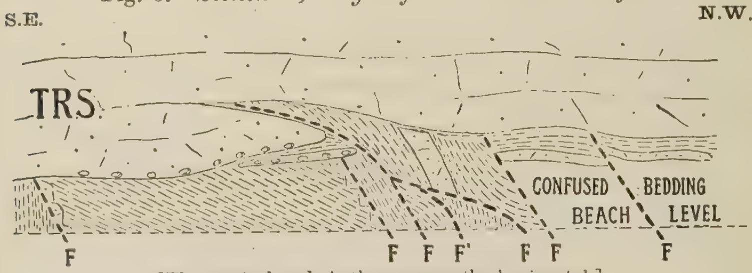
[FF is the fault F′ of fig. 4, hading northward.]

entire cliff-section. Nothing but a diagram and photographs can render this intelligible. (See figs. 6 & 7, p. 536.)

Especially noteworthy here, is the manner in which the lowest layer of the Upper-Sandstone Series seems to have wedged itself plough-like into the superficial portion of the lower denuded beds, and in so doing has bent up the harder bands in the latter to an

angle approaching the vertical. The broken masses of sandstone included in the Lower Series near the line of the unconformity at

Fig. 6.—*Section F; length of section = about 80 feet.*



[The vertical scale is the same as the horizontal.]

Fig. 7.—*Photograph illustrating fig. 6.*

the northern end of the section, seem due to the same order of phenomena; and the whole testifies to movement of the great cliff-sandstone over the edges of the Lower Series in a northerly direction.

Though at first sight strongly suggestive of ordinary faulting, this particular section, on being carefully studied, is, we believe, more reasonably explained by the effects of local irregularities as obstacles in the progress of a horizontal thrust. Pebbles are here again found at the actual base, as well as a little above it in the sandstone. In this, and in some of the highly-disturbed and faulted sections, the whole is so crushed and broken, that it is impossible in places to recognize any prevailing dip.

A few yards north of F a long extent of cliff is reached, in which, except at two narrow spots, the actual unconformity is covered by talus-material; but the Mussel-Band crops out on the beach a few yards from the cliff, and its perfect regularity and parallelism with the Upper Sandstone show that no trace of the disturbance at F is left, and that there can be scarcely any discordance of dip. Indeed, the two small exposures just mentioned prove this to be the case. Pebbles are there seen about a foot above the base of the Table-Rocks Sandstone.

On approaching G the Mussel-Band dips gently northward, to be soon thrown up again by a reversed fault hading in the same direction, so as to abut under the unconformable sandstone, whence it again dips northward at the same angle as before (see fig. 8, p. 538). In this section the pebbles, which are numerous, are only seen on the southern side of the fault which causes the Mussel-Band to override the conglomerate formed by them; consequently, here the Mussel-Band actually overlies a bank of pebbles derived from itself.

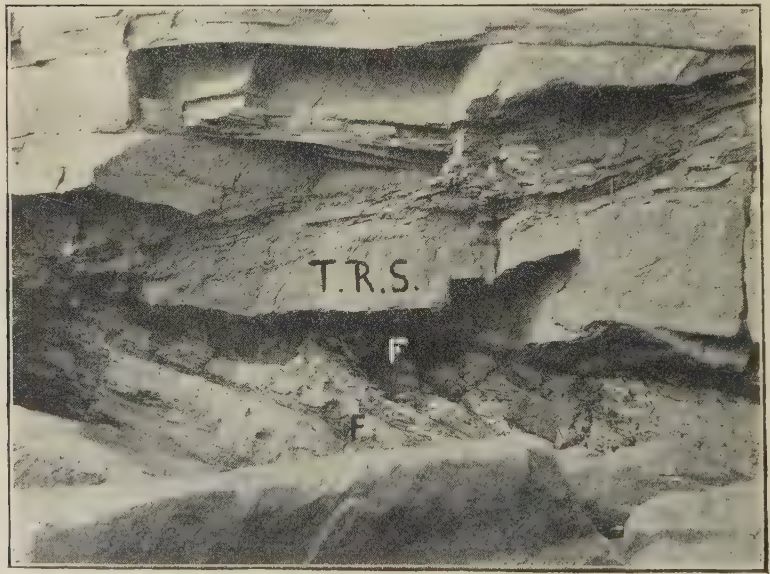
At H the same northerly dip (with absence of pebbles at the unconformity) is observable. Here are two small faults affecting the lower beds, but, of course, stopping short beneath the Upper Sandstone (see fig. 9, p. 538).

Many yards of obscuring talus follow, to be succeeded by a long exposure of perfectly-horizontal Table-Rocks Sandstone, beneath which the lower shales dip at a regular angle of about 15° to the north. Only a few pebbles are to be seen above the junction along this stretch of cliff. This arrangement continues to J. Here is one of the transverse stony ridges to be referred to later on (see p. 546 & fig. 10, p. 539). This little ridge is followed by highly-dipping shaly beds until the Mussel-Band is reached. The latter exhibits a thrust-like disturbance, being sundered by a fracture which causes its southern edge to rear and overtop slightly the northern. Here, as elsewhere, the direction of the movement must obviously have been from south to north. A fault at this place restores the Lower Series of beds to horizontality, with the Mussel-Band running parallel to the Upper Sandstone as before. At K, however, the Lower Series dips sharply to a fault. This fault has little effect, as on its upthrow side the Mussel-Band is once more a few feet beneath the plane of the unconformity, and continues regular, with a slight dip inland, for some 200 yards farther until L is reached. Consideration of a second stony ridge which occurs at K is deferred until later (see *postea*, p. 548).

Fig. 8.—*Section G; length of section = about 15 feet.* (*See p. 537.*)

[The vertical scale is the same as the horizontal.]

Fig. 9.—*Photograph showing the discordance of dip between the Upper and the Lower Series.* (*See p. 537.*)



[FF is a small fault which affects the Lower Series only.]

At L a beautiful little overfold is exhibited in the Mussel-Band and accompanying shales. In the little bay hard by, an interesting reduplication of the Mussel-Band, due to a north-and-south fault,

has quite recently been exposed (November 15th, 1905), as shown in the accompanying sketch-plan (see fig. 11, p. 540).

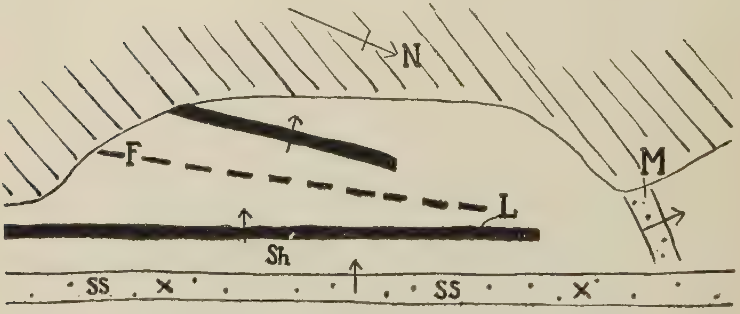
At the northern end (M) of this bay are several parallel stony ridges similar to those described farther on (p. 546). From this point onwards to N, the cliff-section presents a number of complications, which, while they emphasize the evidence in favour of a thrusting movement from south to north, at the same time render it difficult to follow clearly the line of unconformity. The accompanying diagram

Fig. 10.—*Photograph showing the ridge on the foreshore at J.*

[The ridge is marked by two white crosses, and is seen to end abruptly seaward, that is, to the right of the photograph.]

(Pl. XLII) will show the main features of the case better than a detailed description. The difficulty is partly due to the fact that from M northward, the lower course of the Table-Rocks Sandstone loses much of its continuously-massive character, being partly replaced by shale in which tongues of sandstone from the higher portions of the deposit are here and there intercalated, as well as isolated lenticular patches of sandstone. Much of this lower course is also concretionary. Pebbles are fairly plentiful, but appear as a rule to be limited to the bottom of these irregular

Fig. 11.—*Sketch-plan showing the outcrop of the Mussel-Band in the bay near* L. *(See pp. 538–39.)*



[The Mussel-Band is shown in black; SS=Sandstone; Sh=Shale. The heavy broken line indicates a fault.]

Fig. 12.—*(See also Pl. XLII and p. 541.)*

[F F is a fault (FM¹ in Pl. XLII) affecting not only the Lower Series, but also the bottom-course of the Table-Rocks Sandstone. A A is the pebble-bed, and the shales below this dip at a high angle northward. B is a rounded fragment of disturbed shale at the junction of the two series. The dark patch is a little cave weathered out along the fault.]

sandstone-layers. In the latter also occur numerous lenticular pockets of clean coal (locally known as 'scares'), and occasionally of shale. These 'scares' have a characteristic wavy outline, and, although not marked in the other sketches, abound at many places along the coast-section, occurring sometimes up to 6 feet above the base of the Table-Rocks Sandstone. At FM^{I}, and thence to FM^{II}, FM^{III}, FM^{IV}, FM^{V}, and FM^{VI}, are several faults; not, as before, in the series beneath the unconformity, but affecting the lower portions of the Upper Series only. Some of these are rectilinear with ordinary hades; but three (FM^{IV}, FM^{V}, and FM^{VI}) are curvilinear and very flat-haded. All, except the fault at FM^{I}, hade to the south. At N the section closes with a vertical fault which throws the whole of the rocks, both above and below the unconformity. In amount its throw is small, but the fault-fissure is well-marked and filled with clay or 'dowk' (fig. 12, p. 540).

It would seem as if the various appearances exhibited in this line of section may be explained by a certain amount of differential action within the beds above the unconformity, rendered possible only when these are, as in the present case, no longer homogeneous, but of rapidly-changing hardness and texture. Also perhaps in such circumstances a certain, though small, amount of intermingling of the Lower and Upper Series has taken place near the shearing-plane during the general thrusting movement towards the north.

Beyond N, the sandy beach rarely shifts sufficiently to afford many glimpses of the state of things beneath it, and but little information can be gleaned from the low Drift-covered cliffs. Opposite the Convalescent Home, however, some remarkable exposures are at times visible. These show a continuation of the kind of disturbance in the Lower Series of beds, which has been described as commonly occurring in them to the south of M. The Mussel-Band here again furnishes the best evidence at our disposal. Thus, between the water-pipe and the drain-pipe running from the Convalescent Home to the sea, the Mussel-Band is repeated three times by small east-and-west faults, and a little north of this, small anticlinals and isolated outcrops with curved strikes and dipping in various directions are observable, but the connexion between these stratigraphical details is necessarily wanting. There is no evidence whatever of the unconformity north of N.

It may be mentioned that, close to the low-water line immediately to the east of the small, though sharp, disturbances just noted, the strike of the thin sandstones below the Mussel-Band is normal in character, that is, parallel both to the coast-line and to the strike of the Table-Rocks Sandstone, which is here, however, only marked by a small surface-feature, and covered by Boulder-Clay and blown sand. This arrangement—faulted and folded beds west of, and close to, a continuous, unbroken north-and-south outcrop—suggests a strike-fault between the two areas. We have, however, failed to find any good evidence of such a fault, even a small one; and the recognition of the thrusting action renders such a fault unnecessary.

III. The Chemical Evidence.

The Pebbles in the Upper Series.—These have been described as occurring at many places—almost continuously indeed—at and near the base of the Table-Rocks Sandstone. At times, they form a narrow band immediately or a few inches above the unconformity; or again they are found sparsely scattered through a foot in thickness of the sandstone; or, finally, they occur in such numbers as to form a conglomerate many inches thick, as at G. Plant-remains, evidently drifted, and a few shells (*Carbonicola*) are also found, as well as angular and rounded pieces of shale and of the soft fossiliferous parts of the Mussel-Band; but well-rounded pebbles of the harder parts of the Mussel-Band far outnumber the rest of the included fragments of foreign material. The smaller of these well-rounded pebbles are sometimes much oxidized; the larger are slabs several inches thick and measuring up to a foot in diameter, with rounded edges, and containing the typical *Carbonicola*-shells irregularly distributed throughout the mass.

Comparative determinations of the constituents of these pebbles and of the mother-rock were made, with the following results:—

I and II are samples of collections of small pebbles found at F and G respectively.
III is a big pebble from E.
IV is from the Mussel-Band cropping out near G.
V is from the Mussel-Band cropping out near K.

In sampling the last two, the harder parts were selected, as the pebbles are mostly derived from these.

	I.	II.	III.	IV.	V.
Loss on ignition	28·43	28·30	30·74	32·71	32·81
Hygroscopic water	1·38	1·39	1·53	0·88	0·71
Combined water and organic matter ...	5·21	2·05	2·40	4·06	3·94
Insoluble in acids	11·51	12·78	9·12	8·16	7·06
Al_2O_3 (soluble in acids) ...	1·65	0·40	2·44	1·30	0·28
S	0·43	0·55	0·15	0·14	0·13
P_2O_5	0·39	0·29	1·49	0·75	1·01
MnO	0·92	0·97	1·29	1·56	1·35
FeO	35·62	36·90	39·11	32·24	40·93
Fe_2O_3	10·71	6·36	1·34	1·82	0·31
CaO	2·05	4·48	4·60	12·85	9·04
MgO	3·04	4·00	4·36	3·93	2·00
CO_2	25·80	28·96	31·15	31·35	32·71
Alkalies (by difference) ...	1·29	0·87	1·02	0·96	0·53
	100·00	100·00	100·00	100·00	100·00

The residue insoluble in hydrochloric acid from Sample III was found to contain 22·56 per cent. of carbonaceous matter and combined water. The ignited residue contained:—

SiO_2	61·01
Al_2O_3	28·05
Fe_2O_3	4·38
CaO	0·10
MgO	0·90
Na_2O	5·71
	100·15

Turning now to the detailed table of analyses, it will be seen that, while there is a general similarity in the composition of the various samples, Nos. I & II stand apart in some respect from the others, and the differences are such as might be expected to exist between small pebbles on the one hand, and large slabs and the mother-rock upon the other. Thus the insoluble matter is higher in the former case, due to mechanically-mixed sand; sulphur too is high, owing to the presence of pyritic nodules among the pebbles. The phosphorus-content of the small pebbles is lower than that of the Mussel-Band, from which it would appear that some leaching-out of the phosphates took place during weathering. In this connexion, it is noteworthy that the sandstone in which the pebbles are embedded is richer in phosphorus than the overlying pebble-free beds (see *postea*, p. 546). The small pebbles contain more ferric iron and less carbon-dioxide than the other samples, and this is in harmony with the normal weathering of a rock consisting largely of ferrous carbonate. Lime is variable, though on the whole higher in the large slab and the Mussel-Band. Since the lime is derived chiefly from the fossil shells, and since the presence of these makes the rock less able to withstand disrupting influences, it follows that the small pebbles will be mainly made up of the more homogeneous unfossiliferous portions of the rock. Magnesia is remarkably constant in all the samples. A similar phenomenon has been noted in the case of the Cleveland Ironstone, and has been held to be due to uniform dissemination of the magnesia in the form of glauconite.[1] An estimate of the amount of magnesia thus combined is readily obtained by calculating its equivalent to the shortage of carbon-dioxide; that is, the amount of carbon-dioxide still lacking when the acidic oxides have been all appropriated by the basic oxides. In the samples under discussion, it averages about 2 per cent.

It is clear, from the foregoing remarks, that the chemical evidence supports the view that the pebbles are derived from the Mussel-Band. This is brought out more strikingly by the following method of treatment:—

If the pebbles are more or less weathered portions of the Mussel-Band, which itself at its present outcrop is somewhat altered by weathering, then it should be possible, knowing the proximate composition of the rocks in question and the chemical changes which take place during weathering, to calculate the composition of the original rock from which both have been derived.

The only chemical change on weathering which need be considered in the present case, is the oxidation of ferrous carbonate to ferric oxide with loss of carbon-dioxide.

In order to determine the proximate composition of the rocks, we shall assume that the phosphoric oxide exists in combination with ferrous oxide as ferrous phosphate, and that the remainder of the ferrous oxide is present as carbonate; that the manganese is present

[1] R. Tate & J. F. Blake, 'The Yorkshire Lias' 1876, pp. 164 *et seqq.*

as carbonate, since that body is not so easily oxidized as ferrous carbonate[1]; that the lime exists as carbonate, and also that portion of the magnesia for which there is still carbon-dioxide to combine with—the remainder of the magnesia we have already assumed to be present as glauconite. The following table gives the proximate composition of the samples (recalculated for the dry rock). Under the head of 'indifferent constituents' are included ferrous phosphate, combined water, organic matter, insoluble matter, alumina, sulphur, magnesia (present as glauconite), manganese-carbonate, and alkalies; that is, those bodies which would be practically unaltered by such gentle and partial oxidation as takes place during weathering.

PROXIMATE COMPOSITION OF THE SAMPLES.

	I.	II.	III.	IV.	V.
$FeCO_3$	57·71	59·94	62·12	51·50	65·20
Fe_2O_3	10·86	6·45	1·36	1·83	0·32
$CaCO_3$ $MgCO_3$	7·64	12·79	15·22	24·93	16·53
'Indifferent constituents'	23·79	20·82	21·30	21·74	17·95

From this table we can now 'reconstruct,' as it were, the original rock from which the various samples have been derived by weathering. To do this, it is only necessary to replace the ferric oxide by its equivalent of ferrous carbonate, and express the composition of the 'reconstructed' rock in percentages. Thus we get the following table, showing the composition of the 'reconstructed' rocks:—

	I.	II.	III.	IV.	V.
$FeCO_3$	70·00	67·36	63·73	53·74	65·57
$CaCO_3$ $MgCO_3$	7·30	12·43	15·13	24·74	16·51
'Indifferent constituents'	22·70	20·21	21·14	21·52	17·92

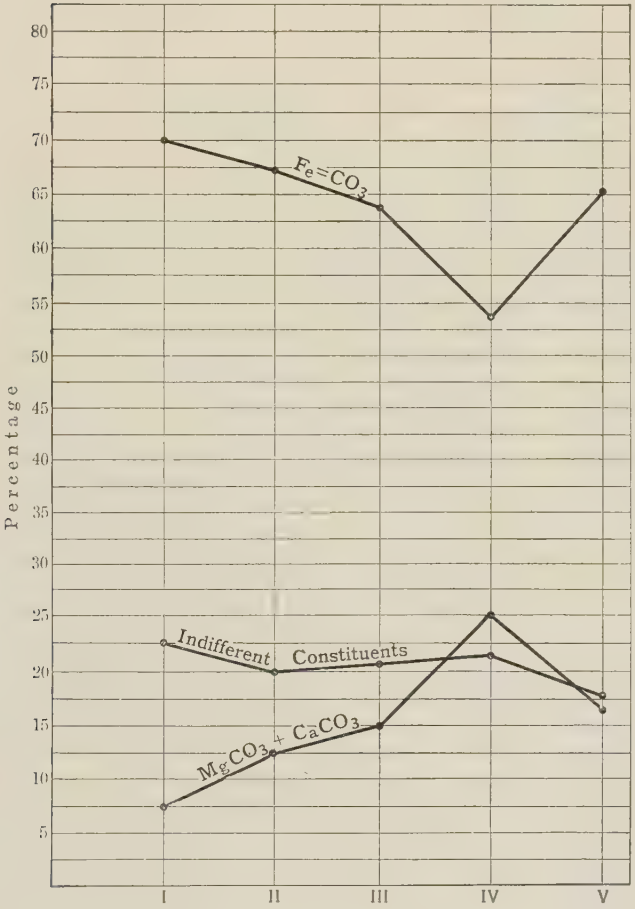
Now, it will be noted that the amount of the 'indifferent constituents' is approximately constant in the five samples, and that the percentages of calcium- and magnesium-carbonates vary inversely as those of the ferrous carbonate. The reconstructed rocks, therefore, differ almost solely, owing to the greater or less replacement of ferrous carbonate by the fossil-making carbonates of calcium and magnesium. Thus, the chemical evidence points to the fact that the Mussel-Band and the pebbles are derived from the same source: the observed differences in composition being due, firstly, to the varying amounts of calcium- and magnesium-carbonates (the result of the irregular distribution of the fossil shells); and, secondly, to the degree of oxidation by weathering which the various samples have undergone.

The appended diagram (fig. 13, p. 545), in which the ordinates represent the composition of the 'reconstructed' rocks, while the

[1] R. Brauns, 'Chemische Mineralogie' 1896, p. 354.

samples are numbered off at convenient lengths on the abscissæ, exhibits clearly the relationships just described.

Fig. 13.—*Diagram exhibiting the relationship in composition between the weathered and the unweathered rocks.*



At the very base, the Table-Rocks Sandstone is extremely hard and compact, and its under-surface, which rests upon the eroded shales, is marked by peculiar knobs and sinuous ridges. This hard rock passes rapidly upwards into the ordinary softer massive sandstone, which when weathered shows concretionary structure on a large scale, the oval segregation-patches being much redder than the surrounding rock. Chemical analysis shows a concentration of

iron and phosphorus in the rock immediately overlying the shales of the Lower Series, thus:—

Analysis (1) of samples from the actual base, and (2) of samples from about 6 feet above the base.

	(1)	(2)
FeO	trace	none
Fe_2O_3	1·43 %	0·91 %
P_2O_5	0·07 %	none.

IV. Conclusions.

From the various facts recited in the foregoing pages, it seems inevitable to conclude that: (1) the beds to which we have referred as the Lower Series suffered a considerable amount of denudation before the Upper Series or Table-Rocks Sandstone was deposited, and that this denuded surface occupied a large area; (2) that after the deposition and consolidation of the Upper Series, a movement took place which thrust that series northwards over the shales and other beds of the Lower Series.

The actual amount of denudation, and the consequent time-value of the unconformity, we have as yet no means of appraising. The actual amount of horizontal displacement or overthrusting we have also, unfortunately, no means of gauging. It seems clear, however, that most, if not all, of the small faults, sharp folds, and other disturbances affecting the Lower Series of beds, are the result of the moving of the Upper Series over them, generally speaking along the pre-existing plane of denudation.

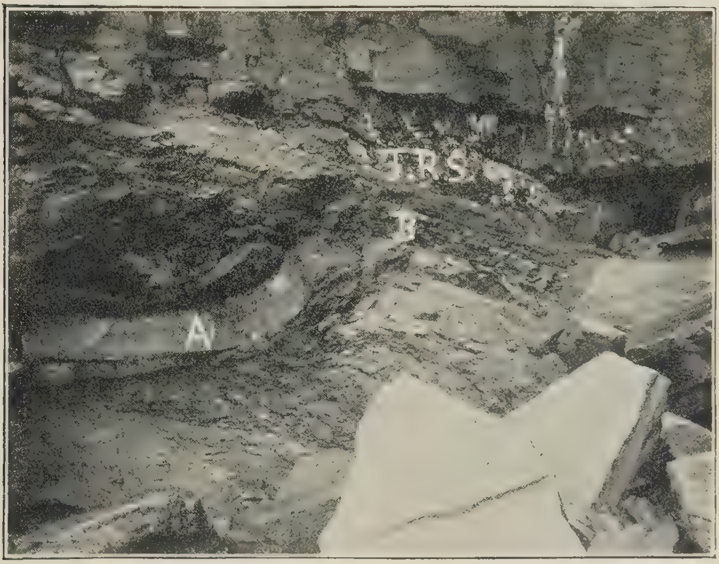
In this case, then, we may regard the thrust as one in which a massive and compact set of rocks was dragged or pushed over a previously-prepared floor chiefly composed of soft, clayey, and, so-to-speak, specially-lubricated material, the nature of the rocks above and below the unconformity providing the required line of least resistance. Where the lubrication was least perfect accidents happened. Thus at F a tongue of Upper Sandstone pierces the shale beneath (see fig. 6, p. 536). At E, the sandstone has been pressed against the hard Mussel-Band and reared up into a fine curl (fig. 14, p. 547).

At several spots the sandstone has ploughed into the shales, hardening and sometimes slickensiding them, as for example on the beach at C, where high-dipping sandstone can be seen resting upon slickensided shale.

The action referred to seems intimately connected with the production of the stony ridges, which have been mentioned as occurring at J, K, and M, and deserve special notice. These ridges consist essentially of outcrops of sandstone belonging to the basement-portion of the Table-Rocks Sandstone, but striking from the base of the cliff, and transversely to it, for some 8 to 10 yards, and intruded dip-wards into the shales of the Lower Series for a distance of 4 to 8 feet. At first sight, these downward-torn apophyses of the Upper Sandstone present the appearance of dykes,

but a careful study of the circumstances leaves little doubt as to their real nature. A few simple diagrams will sufficiently illustrate our explanation (see fig. 15, p. 548). The first of these figures (*a*) shows the mode of occurrence of these ridges in plan. It will be noted that the outcrop of sandstone (of the Lower Series) marked × is entirely unaffected by the ridges, or by the disturbance occasioned by them. The second figure (*b*) shows the actual section parallel to the cliff-line (and parallel also to the general strike of the Table-Rocks

Fig. 14.—*(See fig. 4, p. 535, northern end of the section.) Photograph showing the lowest bed of the Table-Rocks Sandstone (A) curled up and abutting against the Mussel-Band (B).*



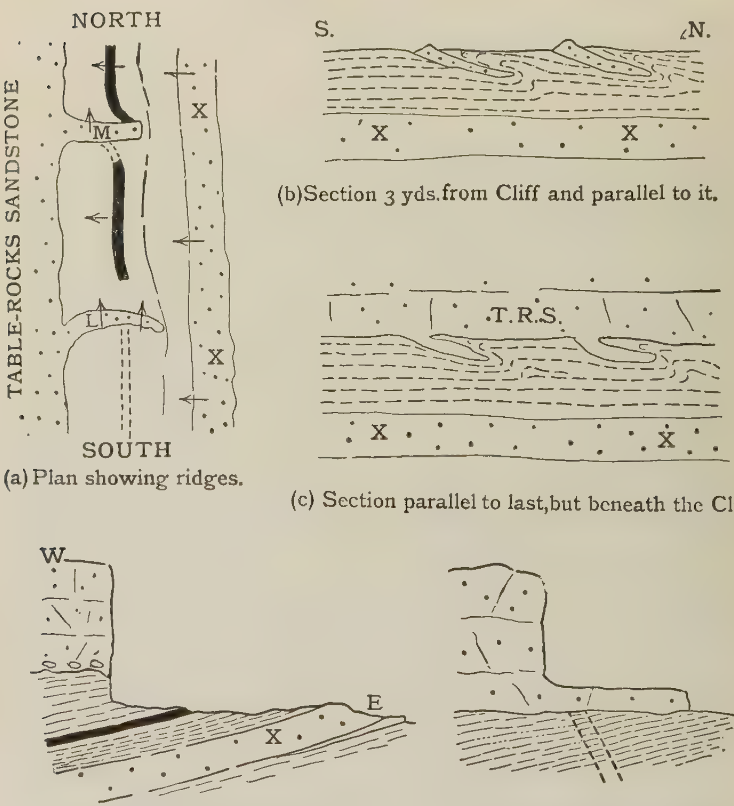
Sandstone) and about 3 yards from it. The third figure (*c*) is one parallel to the last, but representing the probable state of things beneath the cliff. Figures (*d*) and (*e*) show sections at right angles to the cliff-line, one where there is no intruding ridge, and the other along the line of such a ridge. The presence of pebbles in one of the sandstone-ridges at M affords a further confirmation of our interpretation.

The thrusting action is most marked at the junction of the hard and soft beds, that is along the plane of the unconformity. Thus the sandstone-'curl' at E contains pebbles; at F two distinct beds of pebbly sandstone are separated by what is probably squeezed-in, or intruded shale (see fig. 6, p. 536); and at G a mass of

conglomerate, containing pebbles derived from the Mussel-Band, has been forced under the Mussel-Band itself (see fig. 8, p. 538).

In the section from M to N, the pebble-bed has been torn to shreds, and is mixed up with pieces of shale and sandstone, oriented at every conceivable angle. Here too, as has already been pointed out, the movement has extended several feet above

Fig. 15.—*(See p. 547.)*



(a) Plan showing ridges.

(b) Section 3 yds. from Cliff and parallel to it.

(c) Section parallel to last, but beneath the Cliff

(d) Section across the Cliff where there are no ridges

(e) Section across the Cliff where there is a ridge (at K)

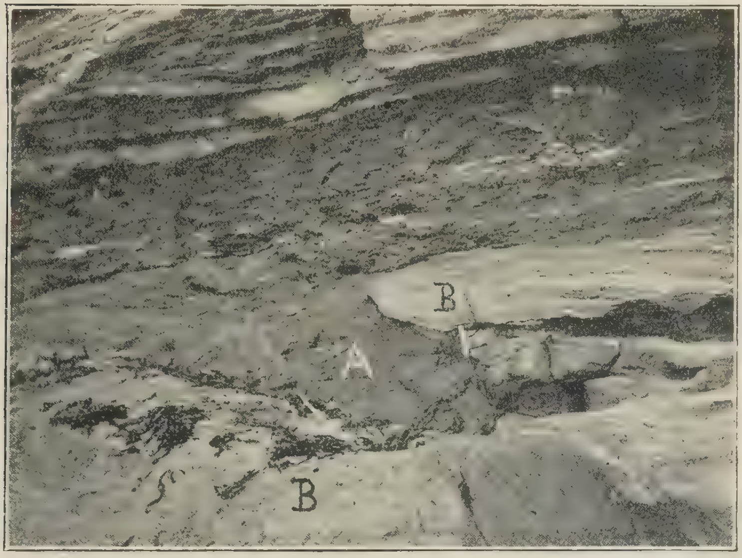
the unconformity, as is shown by the presence of small faults bounded by clay-partings. Where these faults occur, the rock-material is often indescribably shattered and mixed. Where the thrusting coincides least with the unconformity, there the moving mass was least resistant, or in other words most shaly.

As further evidence of the thrust, it may be added that the master-joints of the Upper Series are never continued in the Lower.

Another point worth noting is that the more marked prominences of surface of the Lower Series are invariably those which bear the strongest marks of disturbance.

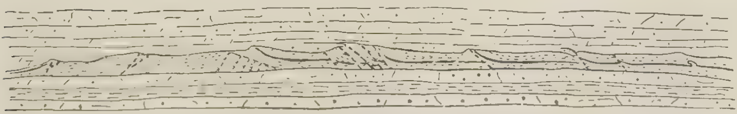
As regards the evidence for the direction followed by the thrusting movement, the chief points have already been mentioned. To these it may be added that the direction of the minor thrusts in the Upper Series (see Pl. XLII) is clearly from south to north;

Fig. 16.—*Photograph showing the direction of the thrust. A = shale, wedged from south to north into the underlying sandstone (B).*



that the small faults transverse to the general line of section are east-and-west faults; and generally that the orientation of disturbed shale-fragments, the motion of which has been arrested by harder beds, also indicates movement from the south (see fig. 16, above).

Fig. 17.—*General section from A to N.*



The action of the thrust is markedly rhythmical, short stretches of highly-disturbed beds alternating with others in which the dip is gentle (see the general section, fig. 17). With the latter disposition.

there is often no noticeable discordance of dip between the two Series, and the pebbles form in such cases about the only means of detecting the unconformity. The stormy episodes are generally marked by the elevation above the general level of the eroded surface of the lower shales. Thus, to some extent, the thrust masks the unconformity, since the wavy uneven outline of the surface of the Lower Series is partly the result of the disturbances caused by the thrust; and, furthermore, violent discordance of dip between the upper and the lower beds, in so far as produced by thrusting, is no criterion of the unconformity.

EXPLANATION OF PLATE XLII.

Section from M to N (see the sketch-map, fig. 1, p. 532), on the scale of about 18 feet to the inch, vertical and horizontal.

Discussion.

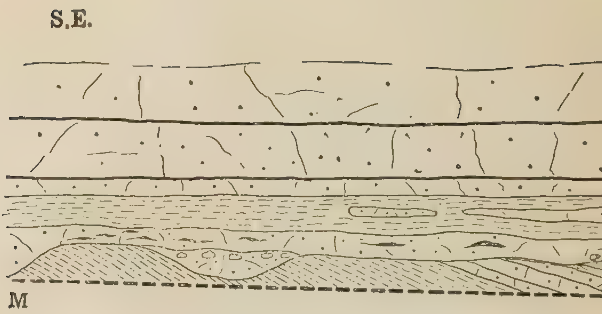
The Chairman (Mr. R. S. Herries) said that the paper once more showed the value of a series of observations conducted over a long period in a particular district.

Mr. Lamplugh complimented the Authors on their clear exposition of this striking example of disruption between 'strong' and 'weak' beds. He was reminded of analogous phenomena in another East-Coast section, on the north side of Flamborough Head, where the massive flinty Chalk had been locally thrust over the more thinly-bedded Lower Chalk. He would ask the Authors whether they had considered the possibility that the supposed pebbles might be due to the breaking-up of the lower beds during the movement.

Mr. Fox Strangways said that the previous speaker had referred to the thrust-plane which occurs at the junction of the flinty Chalk with the non-flinty Chalk in the cliffs of Flamborough Head. As he (the speaker) knew this section very well, he was happy to endorse Mr. Lamplugh's remarks, and to state that the rocks at the foot of Buckton Cliffs appeared to have been subjected to very much the same conditions as those mentioned by the Authors at the base of the Table-Rocks Sandstone; also that the peculiarities noted by them were, no doubt, due to the thrusting of this rock over the beds below.

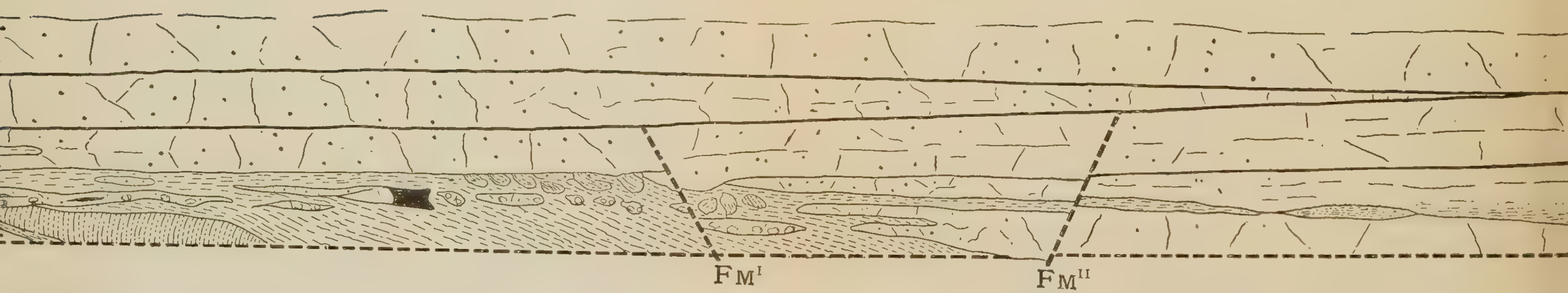
Prof. Watts pointed out that the paper was of considerable interest, because it showed the result of years of denudation on the thrust-plane, which was a common phenomenon at the junction of strong and weak rocks. The Authors seemed to have established the fact of unconformity, and that thrust was insufficient to explain the whole of the phenomena.

Mr. R. H. Tiddeman, without offering an opinion on the suggested unconformity, said that frequently, where Carboniferous sandstone rested on clay or shale, the upper bed contained pebbles of the lower: but such erosion did not necessarily imply any considerable unconformity.

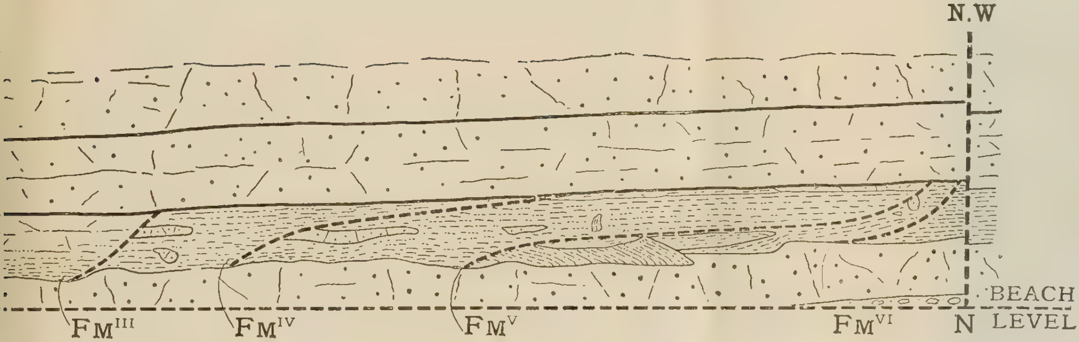


S.E.
M

Section from M to N (see sketch-map, fig. 1, p. 532). Length = about 100 yards. The black patches are ' scare



al.



Mr. J. T. Stobbs said that the North-of-England Institute of Mining & Mechanical Engineers had published a very valuable and unique set of sections of borings and sinkings in connexion with the great Northern Coalfield, for which he believed they were largely indebted to Prof. Lebour. In these volumes the sections of shafts at Whitley, Hartley, Choppington, and West Cramlington record the 'mussel-bands' above the Low-Main Seam, showing that this unconformity had not cut deeper than these bands over a very considerable area. He would like to ask Prof. Lebour whether these facts would not prove helpful in estimating the magnitude of the unconformity.

Mr. Philip Lake said that he was fully prepared to accept the Authors' interpretation, and asked whether the unconformity was accompanied by any palæontological change which might help to determine its magnitude.

Prof. Lebour, in reply, said that it was gratifying to him and his fellow-Author to find that so many had taken part in discussing what, they were afraid, might have been regarded as a dry paper on a merely local question. He would not be surprised if it turned out in the end that every criticism that had been offered was correct—more or less. He did not know for certain whether the coal-seam beneath the plane of disturbance was in truth the Low-Main Seam: it probably was. He had had doubts as to both the unconformity and the thrust, but the evidence detailed in the paper had tended very largely to dispel such doubts. It was probable that even now what he did not know, respecting all the points involved, was considerably more than what he did know. As to the many volumes of North-Country borings and sections referred to by Mr. Stobbs, he could not help knowing them, since he had helped to edit them from the beginning. He knew of no difference between the fossils in the beds above or below the unconformity. The important suggestion made by Mr. Lamplugh was one which had forced itself upon the attention of the Authors long ago; but some of the pebbles were manifestly waterworn, and their long exposure to weathering (in the case of the rolled fragments of mussel-band) seemed to the Authors sufficiently attested by the chemical arguments brought forward in the paper. If Mr. Lamplugh could arrange to visit the section, the Authors would gladly abide by his verdict.

26. Notes *on the* Genera *Omospira*, *Lophospira*, *and Turritoma*; *with* Descriptions *of* New Proterozoic Species. By Miss Jane Donald (Mrs. G. B. Longstaff). (Communicated by Prof. E. J. Garwood, M.A., Sec.G.S. Read May 9th, 1906.)

[Plates XLIII & XLIV.]

In my paper on some of the Proterozoic Murchisoniidæ, Pleurotomariidæ, and Turritellidæ,[1] I referred to the researches of Dr. Ulrich and Prof. Koken among the earlier gasteropoda, and mentioned the groups into which those authors had divided them. We still require much more knowledge with regard to their origin and relationship before really-satisfactory divisions can be made. Unfortunately, the new species that I am about to describe are not sufficiently well-preserved to add much to the material previously available. None of them have the apex entire, and therefore no further light is thrown on the structure of the protoconch. These new species belong to three genera, characterized by the possession of a band on all the whorls, formed by the gradual filling-up during growth of a sinus, and not a slit, in the outer lip. To two of these genera I have already referred, namely, *Lophospira*, Whitfield, and *Turritoma*, Ulrich.[2] The other genus is *Omospira*, Ulrich.[3] Though *Lophospira* and *Turritoma* are not really true Murchisoniidæ, I have allowed them to remain in that family for the present.

Omospira, Ulrich.

Dr. Ulrich places *Omospira* in the family Raphistomidæ, but it is not a characteristic member, for the whorls are more convex and the spire is higher than is the case with the other genera belonging to the family. He describes it thus (*loc. cit.*) :—

'Shell somewhat elongate turbinate, subturriculate; volutions seven or eight, ventricose, obliquely flattened in the upper part by an obtuse shoulder-like angulation; the latter, which may or may not constitute the periphery of the whorls, forms the outer margin of a wide band-like space in which the lines of growth, which first curve strongly backward in their course from the suture-line, are turned in the opposite direction; a short distance before reaching the angle the curve is sharpened; as in *Raphistoma* the junction between the two curves is marked by a thin line, while beneath the outer angle the lines of growth are turned somewhat gently forward. Aperture somewhat quadrate-triangular, its height slightly greater than the width, narrowly rounded but not effuse below; columellar lip rather straight, not thick, usually reflexed so as to hide a minute umbilical perforation. Surface-markings consisting of fine lines of growth only. Type, *O. laticincta*, n. sp. Ulrich.'

Dr. Ulrich considers that *Omospira* was most probably derived from *Raphistoma* or from some unknown allied type, on account of

[1] Quart. Journ. Geol. Soc. vol. lviii (1902) p. 314.
[2] *Ibid.* pp. 330 & 332.
[3] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) 932.

the character of the lines of growth and sinus. Later on,[1] he states that he is not satisfied with the systematic position of *Omospira*, and that

'if *Scalites*, Emmons, could be proved to possess the essential characteristics of the Raphistomidæ, then we would have an undeniable link between *Omospira* and *Raphistoma*.'

Miller[2] regards *Scalites* and *Omospira* as identical: they certainly bear considerable resemblance to one another, but in *Scalites* the upper part of the whorl is much flatter, which gives the spire a step-like appearance, and the whorls are more angular at the periphery. In general form, *Omospira* greatly resembles some members of the Murchisoniidæ and the Pleurotomariidæ, especially such a species as *Hormotoma bellicincta*, Hall, which possesses a sinus. It is distinguished from the typical members of both families by the usually greater relative width of the band, and also by the character of the lines of growth. The lines of growth above are continuous with those on the band, and increase in curvature below, just before the angle, so that they do not form even crescents on the band. In the Murchisoniidæ and Pleurotomariidæ the lines of growth form uniform crescents on the band, and in the true members of each family there is a definite break in their continuity with those above and below. Prof. Koken[3] considers that this genus resembles his *Pseudomurchisonia*, which, however, differs by having the band on the anterior whorls only, and by the lines of growth on the posterior whorls being merely sinuated.

Range.—In America, according to Dr. Ulrich, *Omospira* occurs in the Black-River and Trenton Formations, and may perhaps be represented by a single form in the Upper Silurian. In Britain, I am only acquainted with one species, *O. orientalis*, sp. nov., from the Upper Bala.

Omospira orientalis, sp. nov. (Pl. XLIII, figs. 1, 2, & 2 *a*.)

Diagnosis.—Shell turreted, composed of about seven whorls. Whorls increasing somewhat rapidly, angular near the middle of the body-whorl and below the middle of the earlier whorls, slightly convex above and below—except immediately above the angle, where there is a broad flat band. The angle is not so sharp on the earlier whorls, and the band is there seen to be bounded on each side by a raised thread. This band represents the sinus in the outer lip, which is broad and of moderate depth; the base of the sinus is not evenly concave, but recedes rather more below, immediately above the angle. The lines of growth curve backward to, and forward from, the band with a moderate degree of obliquity; they are distinct, and finer lines are intercalated between stronger ones. The base is convex. There are traces on the body-whorl of a very fine spiral thread a little distance below the angle. Aperture unknown.

[1] Final Rep. Geol. & Nat. Hist. Surv. Minn. vol. iii, pt. ii (1897) p. 944.
[2] 'North American Geology & Palæontology' 2nd Appendix (1897) p. 769.
[3] 'Ueber untersilurische Gastropoden' Neues Jahrb. vol. i (1898) p. 15.

Remarks and Resemblances.—There is one undoubted specimen of this species in Mrs. Gray's collection, and two others which probably belong to it, but they are much crushed and do not show the band or sinus distinctly; the lines of growth, however, indicate that the band was immediately above the angle. One is entirely an internal mould; the other shows some portions of the external mould, as well as the internal. Both the internal moulds have an open umbilicus; but it is impossible to tell from them whether it was so originally, as the test may have filled up the cavity. The best example is somewhat crushed downwards; it has the base of the sinus intact, but, as the whole of the outer lip is not seen, it is probable that the sinus may have been deeper than appears in the figure. Portions of the rock covering the shell have been retained, and by pressing wax into these the form of the sinus, and also of the band on a higher whorl, are better seen than on the specimen itself, which is more or less an internal mould.

This species has somewhat the appearance of a *Lophospira*, but an examination of the band shows it to be quite distinct from any members of that genus. It differs from the two species, *O. laticincta*, Ulrich,[1] and *O. Alexandra*, Billings, referred by Dr. Ulrich to the genus, in the whorl being longer above the angle: this appearance of length is, at any rate, partly increased by the shell being compressed downwards, and it is not so marked on the fifth whorl, which does not seem to have suffered so much by pressure. The band also is not quite so wide in proportion. It comes nearest to *O. laticincta*, where the periphery is more angular than in *O. Alexandra* and the spiral angle is greater.

Dimensions.—Length of the specimen figured, Pl. XLIII, fig. 1, = 24 millimetres; width = 20 mm. Depth of the sinus = about 6·5 mm.

Locality and Horizon.—Thraive Glen (Ayrshire) in the Starfish Bed, a coarse-grained rock of Upper Bala age [Lapworth].

Lophospira, Whitfield.

I gave a brief description of the genus *Lophospira*, Whitfield, in my paper of 1902, and also there described three species. I now propose to discuss it more fully, giving diagnoses of the other British species with which I am acquainted. The genus was created by R. P. Whitfield in 1886,[2] when he gave *Murchisonia bicincta*, Hall, as the type, and his description was afterwards emended by Dr. Ulrich.[3] I here append a diagnosis of the genus, which appears to sum up the chief characteristics.

Diagnosis.—Shell more or less elongated, consisting of numerous whorls. Whorls angular, closely coiled throughout, or only in the earlier stages, the later whorls often becoming disconnected. The

[1] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) pp. 945-46 & pl. lxx, figs. 64-67.

[2] Bull. Amer. Mus. Nat. Hist. vol. i, p. 312.

[3] *Op. supra cit.* pp. 951 & 960.

angle bears the band, which is prominent and frequently trilineate. This band represents a sinus in the outer lip of greater or less depth, which is never prolonged into a slit. The lines of growth curve back to the band above, and forward again below. On it they frequently differ from those above and below, being either stronger or slighter, farther apart, or closer together. Aperture subquadrate, usually longer than wide. The inner lip is generally thickened, often slightly twisted, turning around the umbilicus so as to form a kind of hollow pillar. Ornamentation consisting of keels, sometimes with fine spiral lines in addition.

Remarks and Resemblances.—The character which chiefly distinguishes *Lophospira* from both *Pleurotomaria* and *Murchisonia* is the possession of a sinus, instead of a slit, in the outer lip. This feature also separates it from *Worthenia*, which it otherwise greatly resembles. The band representing the sinus may consist of a blunt edge only, though it is generally trilineate, the central keel being usually the strongest; and it may be developed into a thin undulating flange as in *L. serrulata*, Salt., but sometimes the three keels are nearly equal. The lines of growth on the band may be simple threads of varying degrees of strength, or they may be imbricated, or again they may have a medium incision. Dr. Ulrich[1] considers that *Lophospira* has the most primitive type of sinual band, and that the genus

'is the oldest of the many types strictly belonging to the family Pleurotomariidæ. We say this not so much because the genus goes far back in geological time, for, according to known facts, several other types are equally ancient, but because it shares characters with types belonging to other families which, like the Pleurotomariidæ, originated somewhere in the interval between the Calciferous and the Upper Cambrian.' (*Op. cit.* p. 962.)

He further states that the

'simplicity of the band and apertural notch allies the genus with the Euomphalidæ.'

Some species of *Lophospira* bear a close resemblance to those members of *Trochonema* where the lines of growth are deflected so as to form an apertural notch; but *Lophospira* is always distinguished from that genus by possessing a distinct band. The species of *Lophospira* vary one from the other in the height of the spire, some being considerably elongated, while others are quite short; there is also a difference in the depth of the sinus, and in the degree of obliquity of the lines of growth. Dr. Ulrich has therefore divided them into four sections, and two of these again into several subsections, which he names from characteristic species (*op. cit.* pp. 962–964). These are:—

A. *Perangulata* Section.—Apertural notch >-shaped, deep and wide, the lines of growth sweeping strongly back to the sinual band above and forward again below.

1. *Perangulata* Subsection.—Shells not very high; whorls five to eight, strongly angular. Type, *Lophospira perangulata*, Hall.

[1] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 950.

2. *Bowdeni* Subsection.—Elongated shells; eight to twelve whorls, less angular than in the preceding subsection. Type, *L. Bowdeni*, Safford.
3. *Cicelia* Subsection.—Differs from 1 in having a much more elongated spire, and from 2 in having more numerous and more sharply-angular whorls. Type, *L. cicelia*, Billings.
4. *Serrulata* Subsection.—Distinguished from 1 by the plate-like extension and wavy character of the central keel of the sinual band. Type, *L. serrulata*, Salter.

B. *Bicincta* Section.—Lines of growth curving very slightly, or not at all, backward to the sinual band; sinus very shallow.
1. *Bicincta* Subsection.—Surface-markings fine, generally regular, sharply raised and closely arranged. Type, *L. bicincta*, Hall.
2. *Tubulosa* Subsection.—Similar to the preceding, but the lines of growth are much stronger, lamellose, and imbricating, particularly on the band. Type, *L. tubulosa*, Lindström.
3. *Imbricata* Subsection.—Relatively elevated small shells, with coarsely-lamellar imbricating lines of growth, which indicate a very oblique aperture below the sinual band. Type, *L. imbricata*, Lindström.
4. *Holmi* Subsection.—Lines of growth similar to those of *L. bicincta*, but having the obliquity below the band of those of the *imbricata* subsection. Type, *L. Holmi*, Lindström.
5. *Helicteres* Subsection.—Agrees in all respects with the *bicincta* subsection, excepting that the last whorl or two are free. Type, *L. helicteres*, Salter.

C. *Robusta* Section.—Shells short; whorls more or less convex, ventricose, scarcely angular even at the sinual band, which is distinctly trilineate. Base usually ornamented by rather slight spiral keels. Lines of growth indicating a wide but not very deep sinus in the outer lip. Type, *L. ohioensis*, James.

D. *Trochonemoides* Section.—Like *Trochonema*, except that there is a distinct sinual band. Differs from the usual types of *Lophospira* in the relatively-depressed form, large umbilicus, thick shell, and oblique aperture. Type, *L. trochonemoides*, Ulrich.

These divisions are, perhaps, hardly all of the same value; and they may not all stand ultimately, but they are useful in the present state of our knowledge. The British species with which I am acquainted number fourteen (and there is also one variety): four of these have been previously referred to the genus *Murchisonia*. Some greatly resemble American species; but only one, *Lophospira bicincta*, Hall, can be identified with certainty. Many have the surface so imperfectly preserved, occurring merely as internal or external moulds, that it is difficult to make accurate comparisons. They are referable to three of the sections, and may be tabulated thus:—

A. *Perangulata* Section.
1. *Perangulata* Subsection.—*L. gyrogonia* (M'Coy); *L. excavata*, sp. nov.; *L. variabilis* (Don.); *L. borealis* (Don.); *L. trispiralis*, sp. nov.; *L. instabilis*, sp. nov.; *L. Sedgwickii*, sp. nov.
3. *Cicelia* Subsection.—*L. (?) angulocincta* (Salt.); *L. ferruginea*, sp. nov.

B. *Bicincta* Section.
1. *Bicincta* Subsection.—*L. bicincta* (Hall), var. *scotica*, nov.; *L. bellicarinata*, sp. nov.
2. *Tubulosa* Subsection.—*L. cyclonema* (Salt.); *L. pulchra* (M'Coy).

C. *Robusta* Section.—*L. subglobosa*, sp. nov.

Range.—The British species range from the Durness Limestone up into the Wenlock Limestone. Upwards of fifty species have been

described in America. Dr. Ulrich states that they range from the Calciferous to the Hamilton Group, and considers that the genus attained its maximum of development in the Trenton Period. Ten Silurian species from Gothland, described by Lindström as *Murchisonia* or *Pleurotomaria*, have been referred by Ulrich to *Lophospira*. MM. D.-P. Œhlert describe and figure one species, namely *L. breviculus*,[1] from the Devonian of the Mayenne.

A. *Perangulata* Section.

Perangulata Subsection.

Lophospira gyrogonia (M'Coy). (Pl. XLIII, figs. 3–5.)

Murchisonia gyrogonia, F. M'Coy, 1852, Ann. & Mag. Nat. Hist. ser. 2, vol. x, p. 192; 1852, 'Brit. Palæoz. Foss.' p. 293 & pl. iK, fig. 43; 1854, 'Contrib. Brit. Pal.' p. 243; J. Morris, 1854, 'Catal. Brit. Foss.' 2nd ed. p. 259; J. Sowerby, 1867, 'Siluria' 4th ed. p. 197, Foss. 40, fig. 6, & Appendix p. 532; J. J. Bigsby, 1868, 'Thes. Silur.' p. 158; J. W. Salter, 1873, 'Catal. Cambr. & Silur. Foss.' p. 69; A. C. Ramsay, 1881, Mem. Geol. Surv. vol. iii, 'Geol. N. Wales' 2nd ed. pp. 404, 414, & 431; J. D. La Touche, 1884, 'Geol. of Shropshire' p. 59 & pl. v, fig. 96; R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Palæozoic) p. 113; H. Woods, 1891, 'Catal. Type Foss. Woodwardian Mus.' p. 107; J. Horne & B. N. Peach, 1899, Mem. Geol. Surv. 'Silur. Rocks of Britain' vol. i, p. 682, *non* pp. 699 & 706; J. Horne, B. N. Peach, & A. Macconochie, 1901, in 'Fauna, Flora, & Geology of the Clyde Area,' publ. by Local Comm. for Meeting of Brit. Assoc. Glasgow, ? p. 428, *non* p. 438.

Diagnosis.—Shell rather small, turreted, composed of more than four whorls. Whorls angular, increasing somewhat rapidly, flattened or slightly convexo-concave above, concave below, more or less irregularly coiled, often exsert, last whorl showing a tendency to become detached, sutures frequently very oblique. Sinual band situated on the angle, above the middle of the body-whorl, sub-median on the penultimate whorl; sharp, prominent, almost flange-like, composed of three fine keels. Lines of growth forming distinct threads, strong lines being intercalated between fine ones at tolerably regular intervals, curving obliquely back to the band above and forward below. Ornamentation consisting of a keel on the base at a little distance below the band, which appears above the suture on the higher whorls, when they are exsert; and there are traces of a very fine thread just below the upper suture. Umbilicus closed. Aperture imperfectly known.

Remarks and Resemblances.—There are nine specimens of this species in the Sedgwick Museum, Cambridge, which are all internal moulds. One of them is marked as M'Coy's type; it has the sutures very oblique and the whorls exsert. Another example from the same locality has the sutures less oblique, and there is a slight breakage along the sinual band which gives the appearance of a deep slit in the outer lip, but this has not really existed in the natural state, though the original sinus may have formed a line of weakness which led to the breakage in this part. M'Coy's figure seems to have been constructed from these two individuals: for it has the slit represented on it, and rather more of the base is given than

[1] Bull. Soc. Étud. Sci. Angers, 1887 (sep. cop.) p. 22 & pl. viii, fig. 5.

is actually seen on the specimen marked as the type. The surface-characteristics are not seen on any of these specimens. Mrs. Gray, however, possesses a shell which appears identical with this species, and it has the surface fairly well-preserved. A drawing of it is given (Pl. XLIII, fig. 5). It is compressed obliquely, so that the whorls are caused to appear more oblique and wider from the point of view taken than they must originally have been ; the sinual band on the body-whorl also is so much broken as to give it an undulating appearance. The tricarinate form of the band is shown on part of the body-whorl and also on the penultimate whorl, and the lines of growth are distinctly discernible on parts of the surface. This species resembles *L. perangulata* (Hall)[1] in the structure of the band, the character of the lines of growth, and in the tendency of the last whorl to become detached, but it is distinguished by having a greater spiral angle, and no umbilicus.

Dimensions.—The type (Pl. XLIII, fig. 3) consists of three whorls in a length of 8·25 millimetres, the width = 8·25 mm. Another specimen, figured in Pl. XLIII, fig. 4, having three whorls, = 8 mm. in length, and about 6 mm. in width ; this is less than the full width would be, were the shell not embedded in the matrix. Mrs. Gray's example is also imperfect, and consists of only three whorls. It is figured (Pl. XLIII, fig. 5), and measures 9 millimetres in length and 10 mm. in width. The width here is rendered by pressure greater than it must originally have been.

Locality.—The type and seven associated specimens are from Yspytty Evan (Denbighshire), while another example in the Sedgwick Museum is from the west of Llanfechan (Montgomeryshire). Two other moulds of shells from this last locality are marked *Murchisonia gyrogonia*, but the wax-impression of one shows that the lines of growth pass over the keels without deflection for a sinus, therefore it cannot belong to this species ; and the other is too poor for certain identification. There is a small cast in the British Museum (Natural History) from Meifod, Montgomery, marked *M. gyrogonia*, but it is too badly preserved to make anything of. Mrs. Gray's specimen is from Shallock Mill (Ayrshire). This species has been recorded from other localities in Scotland, but the example referred to here is the only true representative that I have met with. In a previous paper[2] I showed that probably the shells from the Llandeilo of Balclatchie were wholly, or in part, *Lophospira variabilis*, Don.

Horizon.—Middle Bala.

LOPHOSPIRA EXCAVATA, sp. nov. (Pl. XLIII, fig. 6 and text-fig. 1.)

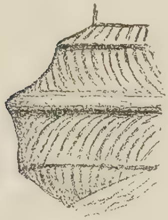
Diagnosis.—Shell turreted, composed of more than four whorls. Whorls increasing at a moderate rate, angular above the middle of the body-whorl and near the middle of the penultimate whorl, deeply concave above the angle, but only slightly concave below. A strong ridge on the angle represents the sinual band, which is

[1] Pal. New York, vol. i (1847) p. 41 & pl. x, fig. 4, *non* p. 179 & pl. xxxviii, figs. 7 *a*–7 *b*.
[2] Quart. Journ. Geol. Soc. vol. lviii (1902) p. 334.

imperfectly known, but was probably trilineate. Lines of growth sharp and regular, curving back to the band above and forward below. Ornamentation consisting of a keel below the suture and another below the band, which is covered by the suture on the earlier whorls. Aperture longer than wide, imperfectly represented. Base produced.

Remarks and Resemblances.—There are four specimens of this species in Mrs. Gray's collection, and two in the Geological Survey Collection, Royal Scottish Museum, which are all imperfectly preserved. The lines of growth are clearly seen on a portion of the surface of one of Mrs. Gray's examples, but not on the band, which is much worn on all the shells; there are traces of a fine line on each side of the central ridge. This species is distinguished from *L. bicincta* (Hall) by the spire being slightly higher, the lines of growth being more oblique below the band, and the band appearing somewhat wider. It greatly resembles *L. obliqua*, Ulr.[1] (*Murchisonia bicincta*, Salt.), but the spiral angle is less, the shell being rather longer in proportion to the width. The whorls are also more excavated above the band than in either of these species.

Fig. 1.—Lophospira excavata, *sp. nov.*, *from the Llandeilo of Minuntion (Gray Collection). Magnified 4 diameters.*



Dimensions.—The specimen figured in Pl. XLIII, fig. 6 has the apex broken, leaving about four whorls which = 20 millimetres in length and 14 mm. in width. The shell, of which a portion of the surface is illustrated in the appended figure, also has the apex broken, and the four remaining whorls = 16 mm. in length and 11 mm. in width.

Locality and Horizon.—Minuntion (Ayrshire), in rocks of Llandeilo age [Lapworth].

Lophospira variabilis, Don.

For description and figures see Quart. Journ. Geol. Soc. vol. lviii (1902) p. 334 & pl. ix, figs. 7–10.

Remarks.—Since writing the description, I have met with ten more specimens of this species, as well as many internal moulds, all in Mrs. Gray's collection.

Lophospira borealis, Don.

For description and figures see Quart. Journ. Geol. Soc. vol. lviii (1902) p. 333 & pl. ix, figs. 5 & 6.

Lophospira trispiralis, sp. nov. (Pl. XLIII, figs. 7 & 7 *a*.)

Diagnosis.—Shell small, turreted, composed of about nine gradually-increasing whorls. Whorls angular, flat or slightly

[1] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 965 & pl. lxxii, figs. 6–8.

concave above, and flat below. Sinual band situated immediately below the angle, which is above the middle of the body-whorl and below the middle of the whorls of the spire; it is broad, and composed of three strong raised threads. The lines of growth curve obliquely back to it above and obliquely forward below, not being observed on the band itself. The ornamentation consists of a strong thread a short distance below the band, and a very fine thread immediately below the upper suture. Umbilicus closed. Base convex. Aperture sub-ovoid, longer than wide; columella nearly straight.

Remarks and Resemblances.—There are about twenty-seven specimens of this species in Mrs. Gray's collection. It is hardly a characteristic *Lophospira*, but seems more like species of this genus than those of *Goniostropha*, Œhlert, to some species of which it also bears a resemblance, more especially to such a form as *Goniostropha Marsi*, Œhl.,[1] from the Devonian. Nevertheless, I consider it advisable to place it in *Lophospira*, until the exact character of the sinual band is known. In the form of the band and ornamentation it is very like *L. instabilis*, which also occurs in beds of the same age, but it is more elongated, having more numerous whorls; the umbilicus is closed, and the lower keel is nearer the band. Among American species it comes nearest to *Murchisonia perangulata*, Hall,[2] from the Trenton Formation, but the band of that species is said to be double, whereas in this the band is formed of three almost equally-strong keels, the lower thread ornamenting the surface is nearer the band, and the upper one is very fine instead of being a distinct keel.

Dimensions.—The biggest specimen has about nine whorls; it is from Thraive Glen, and measures 11 millimetres in length and about 6 mm. in width. It is not so well-preserved as a smaller example from Shallock Mill figured in Pl. XLIII, fig. 7, which consists of eight whorls in a length of 9 mm., whose greatest width = 3·5 mm. Another shell, from Drummuck, the body-whorl of which is figured in Pl. XLIII, fig. 7 *a*, on account of its showing the lines of growth, consists of seven whorls in a length of 5·5 mm., and its width = 3·75 mm.

Locality and Horizon.—Mrs. Gray's collection contains numerous specimens from the Upper Bala of Thraive Glen and of Drummuck, and from the Middle Bala of Shallock Mill (all in Ayrshire).

Lophospira instabilis, sp. nov. (Pl. XLIII, figs. 8–10.)

Diagnosis.—Shell turbinate, composed of about six whorls. Whorls angular above the middle of the body-whorl and near the middle of the earlier whorls, flattish above and nearly vertical below the angle, smooth with the exception of a keel a short distance below the band and a fine thread immediately below the

[1] Bull. Soc. Étud. Sci. Angers, 1887 (sep. cop.) p. 17 & pl. viii, fig. 1.
[2] Pal. New York, vol. i (1847) p. 179 & pl. xxxviii, figs. 7 *a*–7 *b*, *non* pl. x, fig. 4.

suture. Band trilineate, situated on the angle. Lines of growth curving very obliquely back to the band above and forward again below. Sinus in the outer lip triangular, of moderate depth. Base convex and but slightly produced. Indications of an open umbilicus. Test thin.

Remarks and Resemblances.—There are four specimens of this species in Mrs. Gray's collection; and also a fifth example which I am placing with them for the present, as it greatly resembles them, more especially in the form and obliquity of the lines of growth: the surface is, however, not well-preserved and it is much bigger, so it is difficult to be certain of the correctness of the identification. The discovery of better specimens may prove this to be a distinct species, while, on the other hand, if a larger series were found, some might be intermediate in size and prove to be connecting-links with the type. Two of the specimens are represented by both internal and external moulds. The internal mould of one of these is figured in Pl. XLIII, fig. 8; the band has a very sharp keel on the body-whorl, and the bordering keels are only faintly seen on a portion of it; but the three keels are clear on the penultimate whorl, and they are still more distinct on a wax-impression of this whorl taken from the external mould, where the band is wider and the three keels nearly equal in strength. On this shell the base of the sinus in the outer lip appears to be intact, and, judging by the lines of growth, it was probably not originally much deeper than is now represented. The other three examples all show the trilineate band; on one of them (Pl. XLIII, fig. 9) it is not quite so wide, and the central keel is more prominent. The largest specimen (Pl. XLIII, fig. 10) has the three anterior whorls represented by the internal mould, and the posterior ones by the external impression in the matrix. The band is not well-preserved on the body-whorl, where it is a prominent ridge, and the bordering keels are faint. On the third whorl from the base the central keel alone appears, and it is sharp and flange-like. The American species which this most nearly resembles is *L. perforata*, Ulrich[1] (*Murchisonia bicincta?*, Meek & Worthen *non* Hall), but the figures do not give the surface-structure well enough to make a satisfactory comparison.

Dimensions.—The specimen figured in Pl. XLIII, fig. 10, consists of about six whorls, and has a length of 16 millimetres and a width of 13 mm. That represented by fig. 8 in the same plate is imperfect, and consists of about one and a half whorls, which = 8 mm. in length and 10 mm. in width. The wax-impression of this same shell gives three whorls, which = 7·5 mm. in length and 10 mm. in width. That represented by fig. 9 in Pl. XLIII = 12 mm. in length and 8 mm. in width.

Locality and Horizon.—Four of the specimens, including those figured, are from the Upper Bala [Lapworth] of Thraive Glen (Ayrshire). The other is from the Starfish Bed, which is of the same age, and occurs in the same locality.

[1] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 984 & pl. lxxiii, figs. 32–35.

LOPHOSPIRA SEDGWICKII, sp. nov. (Pl. XLIII, figs. 11 & 12.)

Diagnosis.—Shell of medium size, turreted, composed of about seven whorls. Whorls angular, increasing at a moderate rate, flat or slightly concave above the angle, flat below, base convex. A prominent flange-like keel, which represents the sinual band, is situated on the angle above the middle of the body-whorl and is sub-median on the whorls of the spire. Ornamentation consisting of a strong keel a short distance below the band and a very fine thread immediately below the upper suture. No lines of growth discernible. Aperture longer than wide, lip reflected on the columella. Umbilicus small.

Remarks and Resemblances.—In the Sedgwick Museum there are two external moulds from the Mullock-Hill Sandstone, marked '*M. pulchra*, M'Coy $(\frac{b}{414})$,' which are quite distinct from the Irish type of the species, both in form and ornamentation. They more nearly resemble *L. gyrogonia*, M'Coy, in having a prominent flange-like sinual band and a keel a short distance below, but may be distinguished by the smaller spiral angle, minute umbilicus, less oblique sutures, and less exsert whorls, which show no tendency for the body-whorl to become detached. They are also somewhat like *L. perangulata*, Hall, but neither these two specimens, nor six others in Mrs. Gray's collection from the same locality, are sufficiently well-preserved to admit of an accurate comparison being made.

Dimensions.—The largest specimen (Pl. XLIII, fig. 12) in the Sedgwick Museum consists of about six whorls; its length = 13 millimetres, and the width of the penultimate whorl = 7 mm. That figured in Pl. XLIII, fig. 11, belonging to Mrs. Gray, consists of six whorls in a length of 12 mm.; its width = 8 mm. Both the above are external moulds. Another specimen of Mrs. Gray's is partly an internal and partly an external mould; it consists of about seven whorls in a length of 13 mm.; width of penultimate whorl = 6·5 mm.

Locality and Horizon.—Mullock Hill (Ayrshire), in beds of Lower Llandovery age [Lapworth].

Cicelia Subsection.

LOPHOSPIRA ANGULOCINCTA (Salt.).

For description and figures see Quart. Journ. Geol. Soc. vol. lviii (1902) p. 332 & pl. ix, figs. 4 & 4 *a*.

LOPHOSPIRA FERRUGINEA, sp. nov. (Pl. XLIV, figs. 1 & 1 *a*.)

Diagnosis.—Shell turreted, moderately elongated, consisting of about ten whorls. Whorls broad, angular, concave above and flattened below the angle. A prominent obtuse keel is situated on the angle, which is near the middle of the body-whorl and below the middle of the whorls of the spire. This keel is bordered on each side by a fine line, and that it represents the sinus in the outer lip is shown by the lines of growth curving back to it above and

forward again below. There is an additional and slighter keel below on the body-whorl, which is partly visible above the suture on some of the earlier whorls; traces of fine spiral lines are also evident on the surface. Aperture and apex unknown.

Remarks and Resemblances.—Mrs. Gray's collection contains but one specimen, and its surface is only imperfectly preserved. I know of no other species which it resembles. It probably belongs to the *Cicelia* subsection, though it is hardly so slender as the other members of the group.

Dimensions.—Length = 9 millimetres; width = 4·5 mm.

Locality and Horizon.—Ardmillan Brae (Ayrshire), in beds of Llandeilo age [Lapworth].

B. *Bicincta* Section.

Bicincta Subsection.

Lophospira bicincta (Hall). (Pl. XLIV, fig. 2.)

Murchisonia bicincta, J. Hall, 1847, 'Pal. New York' vol. i, p. 177 & pl. xxxviii, figs. 5 *a*–5 *f* (? 5 *g* & 5 *h*); *non* F. M'Coy, 1846, 'Syn. Silur. Foss. Irel.' p. 16 & pl. i, fig. 17; *non* J. W. Salter, 1859, Geol. Surv. Can. 'Canadian Organic Rem.' dec. i, p. 19 & pl. iv, figs. 5–6; *non* Meek & Worthen, 1868, Geol. Surv. Ill. vol. iii, p. 317 & pl. iii, fig. 4. *Murchisonia Milleri*, J. Hall, 1877, Miller's 'Amer. Pal. Foss.' 1st ed. p. 244; non *Pleurotomaria bicincta*, G. Lindström, 1884, 'Silur. Gastrop. & Pterop. Gotl.' Kongl. Svensk. Vet.-Akad. Handl. n. s. vol. xix, no. 6, p. 106 & pl. viii, figs. 15–25. *Lophospira bicincta*, E. O. Ulrich, 1897, Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii, p. 964 & pl. lxxii, figs. 1–5. ? *Murchisonia bicincta*, J. Horne & B. N. Peach, 1899, Mem. Geol. Surv. 'Silur. Rocks of Britain' vol. i. pp. 682 & 695. *Pleurotomaria Milleri*=*Pl. bicincta*, ? B. N. Peach, J. Horne, & A. Macconochie, 1901, in 'Fauna, Flora, & Geology of Clyde Area' publ. by Local Comm. for Meeting of Brit. Assoc. Glasgow, p. 439.

Diagnosis.—Shell turbinate, consisting of more than four whorls. Whorls increasing somewhat rapidly, angular above the middle of the body-whorl and near the middle of the earlier whorls, more concave above the angle than below. Sinual band situated on the angle, narrow, trilineate, the central keel sharp and prominent, the two bordering threads finer. Lines of growth sharp raised threads, curving back to the band above, with a moderate degree of obliquity, almost vertical below. Ornamentation consisting of a strong keel placed below the suture about a third of the distance between it and the band, and another keel at about the same distance from the band below. Body-whorl not much produced. Base convex. Aperture subcircular.

Remarks and Resemblances.—There are two specimens in Mrs. Gray's collection which appear to be this species. I have not had the opportunity of seeing any of Hall's specimens; therefore, in identifying the Scottish shells, I am guided to a certain extent by his figures and description, but more especially by Dr. Ulrich's figures and remarks thereon, as he has had the opportunity of examining a large series of American examples. Dr. Ulrich considers that Hall has united more than one species or variety under the name *bicincta*. The figures evidently differ from one another. Dr. Ulrich therefore sets aside figures 5 *g* & 5 *h* on pl. xxxviii, and regards 5 *a*–5 *f* as

typical of the species. Even then he cannot reconcile Hall's statement, of there being a sharp 'retral curve' of the striæ on the band, with the figure 5 *e*, where the lines indicate a shallow sinus such as Dr. Ulrich has observed to be the case on individuals that he takes as typical *bicincta*. I must also remark that the band is here represented much wider than in his figures of *bicincta*.

I have compared the Scottish specimens with examples of *Murchisonia bicincta*, Salt.,[1] in the British Museum (Natural History), and find that they greatly resemble one another, with the exception that the lines of growth below the band appear slightly more oblique on the latter, a circumstance which has caused Dr. Ulrich to consider it a distinct species, which he has named *Lophospira obliqua*.

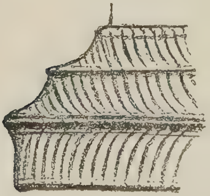
Dimensions.—The specimen figured in Pl. XLIV, fig. 2 has the apex broken; the four remaining whorls = 15 millimetres in length and 12·5 mm. in width. The other example also has the apex broken, and only three whorls remain which = 9·5 mm. in length and 9 mm. in width.

Locality and Horizon.—Balclatchie (Ayrshire), in beds of Llandeilo age [Lapworth]. Messrs. Peach, Horne, & Macconochie record this species from the Llandeilo of Minuntion and the Middle Bala of Shallock Mill in the same county; but I have not met with it in any of the Scottish collections from these localities.

Lophospira bicincta (Hall) var. scotica nov. (Pl. XLIV, figs. 3 & 4 and text-fig. 2.)

This variety resembles the type in every particular, except that the upper keel is about midway between the band and the suture, also there is another slighter keel at the suture, and the shell is generally of greater size. It seems the more abundant form, as there are eight specimens in Mrs. Gray's collection. It resembles *L. humilis*, Ulrich,[2] in ornamentation, but the spire is not so depressed. Dr. Ulrich considers that *L. humilis* is closely allied to *L. bicincta*. Where the outer surface is not well-preserved both on the type and on the variety, the sinual band appears as merely a single strong keel, the finer bordering keels being obliterated.

Fig. 2. — Lophospira bicincta, *var.* scotica *nov., from the Llandeilo of Balclatchie. Magnified 4 diameters.*



Dimensions.—The specimen figured in Pl. XLIV, fig. 3 has the apex broken, leaving only three whorls, which = 18·5 millimetres in length and 16 mm. in width. Width of specimen of which the aperture is shown (Pl. XLIV, fig. 4) = 18 mm.

Locality and Horizon.—Balclatchie (Ayrshire), in beds of Llandeilo age [Lapworth].

[1] Geol. Surv. Canada, 'Canadian Organic Remains' dec. i (1859) p. 19 & pl. iv, figs. 5–6.

[2] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 968 & pl. lxxii, figs. 12–15.

Lophospira bellicarinata, sp. nov. (Pl. XLIV, fig. 5 & text-fig. 3.)

Diagnosis.—Shell turreted, composed of more than six whorls. Whorls strongly angular above the middle of the body-whorl, and slightly below the middle of the earlier whorls; surface deeply excavated above the angle and more or less concave below. Sinual band situated on the angle, having a very prominent central keel and a slighter one bordering a groove on each side. Ornamentation consisting of a keel a short distance below the upper suture, and another below the band which appears just above the lower suture on the anterior whorls of the spire. Lines of growth strong and distinct, curving back to the band above and coming down almost vertically below, forming crescents on the band which indicate a sinus of moderate depth. Base convex. Aperture imperfectly known, produced; no indication of an open umbilicus. Test thin.

Fig. 3. — Lophospira bellicarinata, *sp. nov., penultimate whorl magnified 3 diameters. From the Middle Bala of Shallock Mill.*

Remarks and Resemblances. — Mrs. Gray's collection contains two specimens of this species: that figured in Pl. XLIV, fig. 5 is fairly well-preserved, the other is very imperfect. Among British shells it most nearly resembles *Pleurotomaria turrita*, Portl.,[1] but is distinguished by the central keel of the band being more prominent, the upper and lower keels being stronger, the whorls more excavated above, and the lines of growth being less oblique. The American species which it is most like is *L. Saffordi*, Ulrich,[2] from which it differs in being rather slighter, the band somewhat wider, its central keel sharper and more prominent, and the lines of growth less oblique.

Dimensions.—Length of specimen figured, consisting of five whorls, = 30 millimetres: width of penultimate whorl = 16 mm. The other example is smaller, and consists of about six whorls in a length of 17 mm.

Locality and Horizon.—Shallock Mill (Ayrshire), in rocks of Middle Bala age [Lapworth].

Tubulosa Subsection.

Lophospira cyclonema (Salt.). (Pl. XLIV, figs. 6–9.)

Murchisonia cyclonema, J. W. Salter, 1873, 'Catal. Cambr. & Silur. Foss.' p. 155. *Murchisonia corpulenta*, W. J. Sollas, 1879, Quart. Journ. Geol. Soc. vol. xxxv, p. 499 & pl. xxiv, fig. 11; A. C. Ramsay, 1881, Mem. Geol. Surv. vol. iii, 'Geol. North Wales' 2nd ed. p. 461; R. Etheridge, 1888, 'Foss. Brit. Is. vol. i (Palæozoic)' Appendix, p. 418. *Murchisonia cyclonema*, H. Woods, 1891, 'Catal. Type Foss. Woodward Mus.' p. 107. *Pleurotomaria cyclonema*, F. R. C. Reed, 1901, Geol. Mag. dec. iv, vol. viii, p. 248 & pl. xi, figs. 1–3.

Diagnosis.—Shell somewhat short, robust, turbinate, composed

[1] 'Rep. Geol. Londonderry, &c.' 1843, p. 413 & pl. xxx, fig. 7.

[2] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 982 & pl. lxxiii, figs. 49–51.

of about six whorls. Whorls increasing somewhat rapidly, more or less convex. Band prominent, situated considerably above the middle of the body-whorl, and near the middle of the penultimate whorl, of moderate width, bounded on each side by a raised thread, with a stronger thread which is submedian, being placed either in the middle or else nearer the upper thread. Ornamentation above the band, consisting of a strong, rounded keel about midway between it and the suture and a swelling immediately below the suture; consisting below the band on the body-whorl of six or more strong rounded keels, the uppermost being the strongest, and from one to three showing on the higher whorls above the suture. Lines of growth distinct, sharply defined, fine threads curving back to the band above, coming forward immediately below the band and then curving slightly backward, forming strong raised crescents on the band, indicating a sinus of moderate depth in the outer lip. Aperture sub-circular, the inner lip slightly reflected, either adpressed on the body-whorl or free. Base convex. Umbilicus closed.

Remarks and Resemblances.—The first to record this species is Salter in 1873, but he does not describe or figure it. In 1879 Prof. Sollas describes and figures it under the name of *Murchisonia corpulenta*; he has but one example, which is poorly preserved, and he does not refer to Salter's previously-named specimens. Mr. F. R. Cowper Reed in 1901 describes and figures Salter's species as *Pleurotomaria cyclonema*, but does not identify it with that of Prof. Sollas. Through the kindness of Prof. Hughes and also of the Committee of the Bristol Museum in lending me the specimens, I have been enabled to compare them, and I am convinced of their identity. As Salter's name is the oldest, and the species is founded by him on a good representative series of fourteen individuals, and has also since been accurately described and figured by Mr. F. R. C. Reed, it seems best that Salter's name should stand (though he did not give a description or figure)—more especially as the specimen figured by Prof. Sollas is a poor one, unsuitable for a type, and not characteristically represented on the plate. The lines of growth indicate a sinus, and not a slit, in the outer lip. On some examples they are coarse and sub-lamellar, on others they are fine and closely packed, while on others again they vary in strength and nearness on the same individual. Those on the band are either crescentic or subquadrate in form; they may be similar to those on the rest of the shell, or they may differ in strength and closeness together. The fact of this species having a sinus in the outer lip, together with its other characteristics, necessitates its removal from the genus *Murchisonia* to *Lophospira*, where it must be placed in the *Tubulosa* subsection of the *Bicincta* section. It greatly resembles *Pleurotomaria laqueata*, Lindström,[1] which Dr. Ulrich also places in the same group, but it differs in the character of the band. I have met with twenty-seven specimens of this

[1] 'Silurian Gastropoda & Pteropoda of Gotland' Kongl. Svensk. Vet.-Akad. Handl. n. s. vol. xix, no. 6 (1884) p. 102 & pl. ix, figs. 4–6.

species, fourteen of which are in the Sedgwick Museum, Cambridge, nine in the British Museum (Natural History), three in the Museum of Practical Geology, London, and one in the Bristol Museum.

Dimensions.—The specimen that would have been the largest if entire is in the Sedgwick Museum, Cambridge; it has barely three whorls, but has the aperture remarkably well preserved; it has already been figured by Mr. F. R. Cowper Reed, and is figured again (Pl. XLIV, fig. 7) in order to show the inner lip adpressed against the body-whorl. It measures 34 millimetres in length and 26 mm. in width. An example nearly as large in the same collection has the apex broken, leaving four whorls which = 36 mm. in length and 25 mm. in width. The smallest individual in this collection has four whorls in a length of 10 mm., whose greatest width = about 8·5 mm. The specimen of Prof. Sollas, figured in Pl. XLIV, fig. 6, consists of five whorls in a length of 35 mm., the width measuring 27 mm. In another example with the aperture, which is in the British Museum (Natural History), figured in Pl. XLIV, fig. 8, the inner lip appears detached, as is frequently the case in *Lophospira*; but perhaps this is due to the state of preservation.

Locality and Horizon.—The specimens in the Sedgwick Museum and seven in the British Museum are from Dudley. That in the Bristol Museum is from Cae Castell, Rhymney River. Three in the Museum of Practical Geology are severally from Callow Farm, Martley (Worcestershire); the Herefordshire Beacon; and Wenlock Edge. The horizon of all these is the Wenlock Limestone, of which formation *L. cyclonema* appears to be a characteristic fossil, as hitherto I have not met with it elsewhere.

Lophospira pulchra, M'Coy. (Pl. XLIV, figs. 10 & 11.)

Murchisonia pulchra, F. M'Coy, 1846, 'Syn. Silur. Foss. Irel.' p. 16 & pl. i, fig. 19; ? 1852, 'Brit. Palæoz. Foss.' p. 294 & pl. i K, fig. 42; J. Morris, 1854, 'Catal. Brit. Foss.' 2nd ed. p. 259; J. Sowerby, 1867, 'Siluria' 4th ed., Appendix, p. 532; J. J. Bigsby, 1868, 'Thes. Silur.' p. 159; *non* J. W. Salter, 1873, 'Catal. Cambr. & Silur. Foss.' pp. 69 & 83; A. C. Ramsay, 1881, Mem. Geol. Surv. vol. iii, 'Geol. N. Wales' 2nd ed. pp. 404, 414, 431 & 437; R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Palæozoic) p. 113; *non* H. Woods, 1891, 'Catal. Type Foss. Woodward. Mus.' p. 107; *non* J. Horne & B. N. Peach, 1899, Mem. Geol. Surv. 'Silur. Rocks of Britain' vol. i, p. 682; *non* B. N. Peach, J. Horne, & A. Macconochie, 1901, in 'Fauna, Flora, & Geology of the Clyde Area' publ. by Local Comm. for Meeting of Brit. Assoc. Glasgow, p. 438.

Diagnosis.—Shell of medium size, subconical, composed of about seven whorls. Whorls increasing at a moderate rate, subangular near the middle of the penultimate whorl, and below the middle of the body-whorl, flattened or scarcely convex above, slightly convex below. Band situated on the angle, prominent, rather convex, margined on each side by a raised thread, with another thin thread down the middle. Ornamentation consisting of a thread immediately below the suture, and another stronger one a short distance below the band. Lines of growth strong, sublamellose, sharply bent on the uppermost keel, curving back to the

band with but a slight degree of obliquity, strongly concentric or subquadrangular on the band and passing downwards almost vertically. Sinus probably of moderate depth. Aperture subquadrate; columella slightly twisted back; inner lip apparently reflected on the body-whorl.

Remarks and Resemblances.—The types of this species, as described and figured by M'Coy in the 'Syn. Silur. Foss. Irel.', are in the Museum of Science and Art, Dublin. They occur as external moulds, and the drawings are made from wax-impressions. M'Coy describes a variety of this species in his 'Brit. Palæoz. Foss.' p. 294, which is figured from an Irish specimen, as he considers it better preserved than the English examples. This figure consequently agrees with the specimens in the Dublin Museum. Through the kindness of Prof. Hughes, I have been enabled to examine the specimens in the Sedgwick Museum referred to as being a variety of *L. pulchra* by M'Coy, with the exception of the example from Alt-yr-Anker, Meifod, which appears to be missing. They are all external moulds, and none of them resemble this species sufficiently to be considered a variety of it. That from the Middle Bala slates north of Tremadoc is too poor to make anything of. The specimen from the Llandovery of Mathyrafal is not a *Lophospira*, as the lines of growth pass over the submedian keel without being deflected to form a sinus. Those from the Llandovery of Mullock Quarry, Dalquorhan, constitute a new species of *Lophospira*. The only British species which *L. pulchra* resembles is *Ulrichospira similis*, Don.,[1] but there the band is grooved, the ornamentation is different, and the lines of growth make more concave curves. *L. pulchra* bears some likeness to *L. medialis* var. *burginensis*, Ulrich,[2] in its general contour, form of band, and lamellose lines of growth; but it differs in having less oblique lines of growth, a decided keel below the suture on which these lines are acutely bent, and no umbilicus. None of the specimens in the Museum of Practical Geology, London, marked *Murchisonia pulchra* agree with this species; neither have I seen any undoubted representatives of it in Mrs. Gray's collection, nor in the Geological-Survey Collection, Edinburgh.

Dimensions.—The specimen figured in Pl. XLIV, fig. 10, consists of seven whorls = 16 millimetres in length, and the penultimate whorl = 9·5 mm. That which is figured in Pl. XLIV, fig. 11, consists of portions of two whorls, which measure 9·5 mm. in length and 9·5 mm. in width.

Locality and Horizon.—M'Coy states that this species is very common in the grey slate resting upon trap at Glencraff, Leenane (Co. Galway). I am informed by Mr. McHenry that this rock is of Wenlock age.

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 569 & pl. xxxvii, fig. 3.

[2] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 974 & pl. lxxiii, figs. 30–31.

C. *Robusta* Section.

Lophospira subglobosa, sp. nov. (Pl. XLIV, fig. 12 & text-fig. 4.)

Diagnosis.—Shell short, turbinate, composed of several whorls. Whorls increasing somewhat rapidly, slightly convexo-concave above, convex below. Sinual band situated above the middle of the body-whorl and rather below the middle of the penultimate whorl, almost even with the surface, but slightly margined and having a submedian line. Lines of growth forming strong raised threads, curving back to the band above and passing down nearly vertically below, forming crescents on the band where finer lines are intercalated among the strong ones, indicating a shallow sinus in the outer lip. Surface smooth, with very faint indications of spiral lines. Test thin. Aperture unknown.

Fig. 4. — Lophospira subglobosa, *sp. nov., from the Llandeilo of Craighead, magnified 2 diameters.*

Remarks and Resemblances. — I have only met with three specimens of this species, which are in Mrs. Gray's collection and are all imperfect; one shows the surface-ornamentation very well, and there are traces of it on the others. This species bears the characteristics of the *Robusta* Section of Ulrich, and is very different from the typical species of *Lophospira*, the whorls being more convex and not having the accessory keels with which members of the genus are generally ornamented. It resembles *Pleurotomaria robusta* var. *lævissima*, Lindstr.,[1] but the whorls are not so convex, the band is not so distinctly margined, and the lines of growth are less oblique.

Dimensions.—Portions of two whorls are preserved in two specimens, and only a fragment of one whorl in another. That figured in Pl. XLIV, fig. 12, measures 25 millimetres in length and 36 mm. in width.

Locality and Horizon.—Craighead (Ayrshire), in beds of Llandeilo age [Lapworth].

Turritoma, Ulrich.

I have already given Dr. Ulrich's diagnosis[2] of this genus, and have provisionally referred to it two species, namely *T. (?) polita* and *T. (?) pinguis*. I could only place these species here provisionally as they do not exactly agree with the diagnosis, nor do they resemble in contour the figure of the type-species, *Murchisonia acrea*, Billings, which unfortunately is represented very imperfectly.

[1] 'Silurian Gastropoda & Pteropoda of Gotland' Kongl. Svensk. Vet.-Akad. Handl. n. s. vol. xix, no. 6 (1884) p. 104 & pl. viii, figs. 8–9.

[2] Quart. Journ. Geol. Soc. vol. lviii (1902) p. 330.

They resemble, however, some of the other species associated with it by Dr. Ulrich, more especially *M. Laphami*, Hall, which have more or less flattened instead of concavo-convex whorls and the band situated low down, features which Dr. Ulrich states in his remarks are characteristic of the genus. When a better specimen of *Turritoma acrea* is figured, should these shells with uniformly-flattened whorls be found not to agree with it essentially, they must constitute a new genus. *Hormotoma cingulata*, His., as already mentioned,[1] and perhaps *H. dubia*, Don., should be referred here, and also a new and closely-allied species which I am about to describe as *Turritoma (?) tenuifilosa.*

This group bears a great resemblance to, and probably may contain, the progenitors of the Devonian *Cœlidium*, Clarke & Ruedemann[2] [*Cœlocaulus*, Œhlert], but it differs from the type of the genus, *C. Davidsoni*, Œhl.,[3] in having the sinus in the outer lip deeper, the obliquity of the lines of growth much greater, the base of the shell more flattened, and the outer lip not appearing reflected as in M. Œhlert's figure.

As the validity of a species depends in a great measure on the number of forms by which it is represented, I may here state that Mrs. Gray has ten specimens of *T. (?) pinguis* from the Upper Bala of Thraive Glen, in addition to those already mentioned. There is also an example in the Geological-Survey Collection, Edinburgh, from the same horizon at Drummuck Burn.

TURRITOMA (?) TENUIFILOSA, sp. nov. (Pl. XLIV, figs. 13 & 13 *a*.)

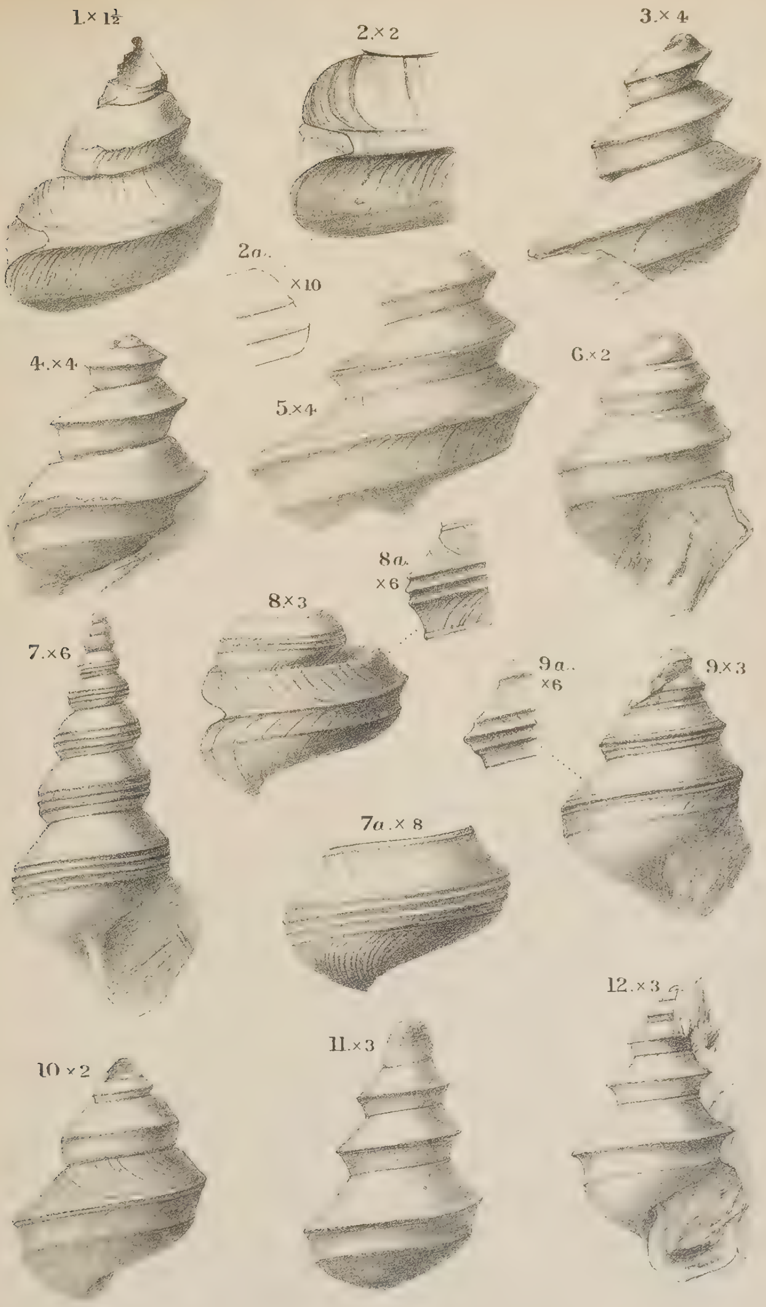
Diagnosis.—Shell somewhat elongated, conical, composed of more than seven whorls. Whorls flattened, but slightly convex, broad, ornamented by numerous fine spiral threads. Sinual band situated considerably below the middle of the upper whorls, slightly grooved, limited on each side by a raised thread. Lines of growth curving very obliquely back to the band above, indistinctly below, and invisible on the band itself. Aperture subovoid. Base apparently rather flattened. Test very thin.

Remarks and Resemblances.—There is but one example of this species in Mrs. Gray's collection, and it is crushed and embedded in the matrix. The body-whorl appears more angular than it must originally have been, owing to its being flattened by pressure; the outline of the other whorls is also probably rendered less convex by the same cause. It greatly resembles *T. (?) polita*, Don., but the base is more angular, the band is situated slightly higher on the whorls, and the surface is ornamented by fine spiral lines. It is also like *Hormotoma cingulata*, His., in the flatness of the whorls, thinness of the test, and in being ornamented by fine spiral lines, but is distinguished by its less elongated form.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 265.

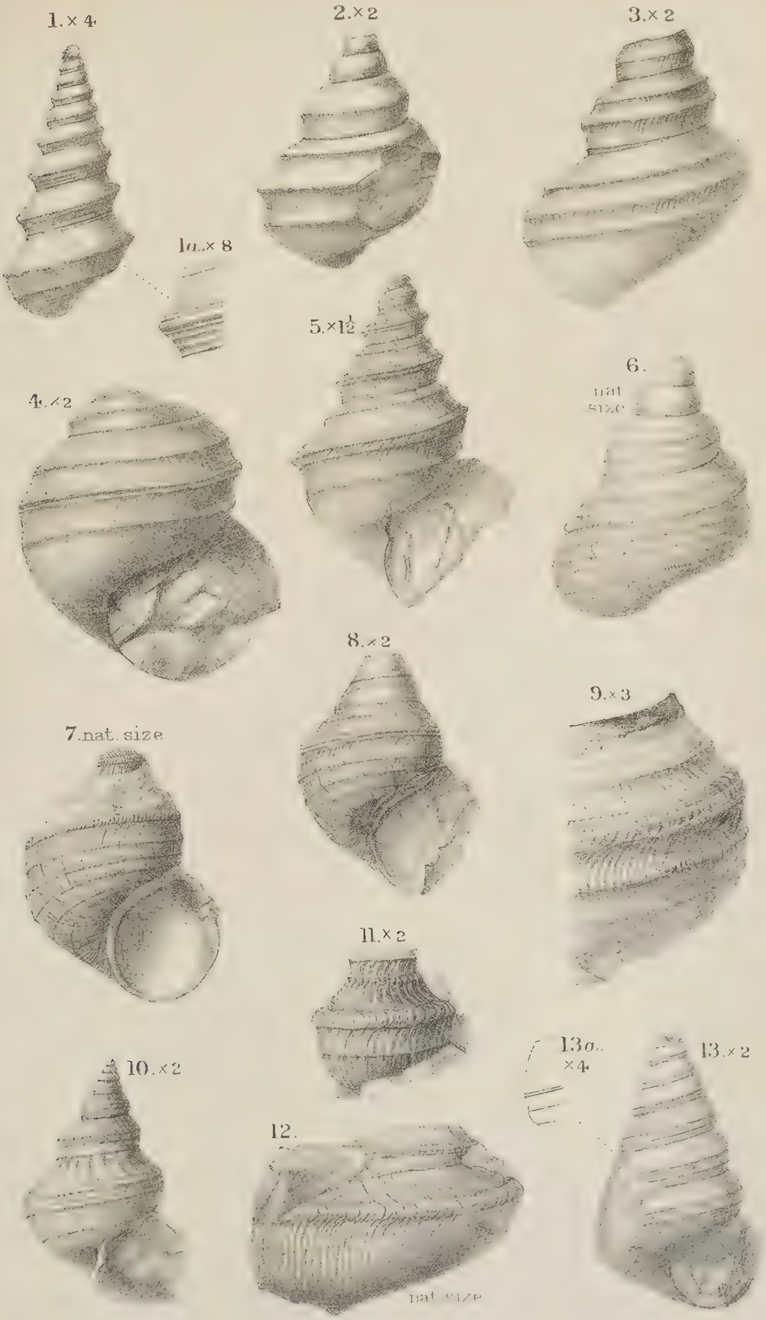
[2] N. Y. State Mus. Mem. 5, 'Guelph Fauna in the State of New York 1903, pp. 65–67.

[3] 'Description de qq. Esp. dévoniennes de la Mayenne' Bull. Soc. Études Sci. Angers (1887) p. 21 & pl. vii, figs. 4–4 *d*. (4 *e* on the plate would seem to be a misprint for 4 *c*.)



J. Donald del. F. H. Michael lith. Bale & Danielsson, L^td imp.

PROTEROZOIC SPECIES OF OMOSPIRA AND LOPHOSPIRA.



J. Donald del. F. H. Michael lith.

Bale & Danielsson, Ltd imp.

PROTEROZOIC SPECIES OF LOPHOSPIRA AND TURRITOMA.

Fig. 5. *Lophospira bellicarinata*, sp. nov. Front view, × $1\frac{1}{2}$. Shallock Mill (Ayrshire). Gray Collection.

Figs. 6–9. *Lophospira cyclonema* (Salt.). Fig. 6. Back view of the type of *Murchisonia corpulenta* (Sollas). Nat. size. Cae Castell, Rhymney (Glamorgan). Bristol Museum. Fig. 7. Front view of specimen showing aperture. Nat. size. Dudley. Sedgwick Museum, Cambridge. Fig. 8. Front view of another specimen with aperture, × 2. Dudley. British Museum (Nat. Hist.). Fig. 9. Portion of whorl of another specimen showing lines of growth, ×3. Dudley. Sedgwick Museum, Cambridge. Drawn from a photograph.

Figs. 10 & 11. *Lophospira pulchra* (M'Coy). Fig. 10. Front view of wax-impression, × 2. Fig. 11. Back view of wax-impression, × 2. Glencraff, Leenane (Co. Galway). Museum of Science and Art, Dublin. Drawn from photographs.

Fig. 12. *Lophospira subglobosa*, sp. nov. Back view, nat. size. Craighead (Ayrshire). Gray Collection.

13. *Turritoma (?) tenuifilosa*, sp. nov. Front view of specimen flattened by pressure, × 2. Fig. 13 *a*. Outline of penultimate whorl, × 4. Woodland Point (Ayrshire). Gray Collection.

27. Liassic Dentaliidæ. By Linsdall Richardson, F.G.S. (Read March 7th, 1906.)

[Plate XLV.]

The Great Western Railway-line between Honeybourne and Cheltenham now (1906) nearing completion, necessitated the making of a considerable number of cuttings in the Lias, the zones exposed dating from *oxynoti* to *capricornus* inclusive. Among the fossils collected were many belonging to the family Dentaliidæ. The majority of the forms appeared to be new, and consequently a somewhat exhaustive investigation of the Liassic members of the family was imperative. In the course of these investigations, through the courtesy of the respective keepers, the specimens preserved in the Natural History Museum, the Museum of Practical Geology (Jermyn Street), the Geological Society's Museum (Burlington House), the Sedgwick Museum (Cambridge), and the Bath Museum, have been examined.[1]

Occasionally some difficulty arises in distinguishing the tubes of certain tubicolous annelids of the genus *Ditrupa* from those of the Dentaliidæ; but, if the less regular character of the tubes does not suggest their true zoological position, a microscopic investigation will in most cases soon elucidate matters. The shells of scaphopods are of course open at both ends, which is not the case with those of the Serpulidæ.

It may be of interest to mention that the growth of the scaphopod-shell is effected by means of successive increments at the anterior end, while contemporaneously the posterior end suffers by wear and absorption. The members of this class (Scaphopoda) are essentially marine organisms, and for the most part inhabit deep water, being embedded in the mud or sand with only the posterior end of the shell projecting above the surface. There are no littoral species, and their food consists principally of foraminifera.

In this paper it is not purposed to enter into the sub-generic division of *Dentalium*: the term is employed in the broad sense.

In the memoir on 'The Lias of England & Wales (Yorkshire excepted),' published by the Geological Survey in 1893, the species of *Dentalium* recorded from the Lias of this country are:—*Dentalium angulatum*, J. Buckman, *D. elongatum*, Münster, *D. etalense*, Terquem & Piette, *D. giganteum*, Phillips, *D. liassicum*, Moore, *D. limatulum*, Tate, *D. minimum*, Strickland, and *D. tenue*, Portlock: *D. gracile*, Moore, *D. compressum*, d'Orbigny, and *D. trigonale*, Moore, being regarded as synonyms of *D. elongatum*, and *D. Portlocki*, Tate, of *D. etalense*. The new species made in this paper are *Dentalium acutum*, *D. hexagonale*, *D. oblongum*, *D. parvulum*, *D. suboratum*, *D. subtrigonale*, *D. subquadratum*, and *D. Terquemi*. Moore's *D. trigonale* is found to be a valid species; but *D. tenue*, Portlock, and

[1] There are no examples of *Dentalia*, either in the Worcester Museum, or in that of the Royal Agricultural College at Cirencester.

D. Portlocki, Tate, are probably synonymous with *D. minimum*, Strickland - Buckman. Probably *Dentalium filicauda opalina*, Quenstedt, will ultimately be found to be distinct from *D. elongatum*; if so, the Liassic species of *Dentalia* will be seventeen in number, and this without taking into consideration the question as to whether certain varieties of *Dentalium parvulum* and *D. elongatum* are sufficiently distinct to rank as species.

DENTALIUM ACUTUM, sp. nov. (Pl. XLV, figs. 10 & 11 *a–d*.)

Type-locality (*T.l.*).[1]—Railway-cutting, 'Dixton West,' near Gotherington, near Cheltenham.
Horizon (*H.*).—Pliensbachian.
Hemera (η).—*striati.*
Collection (*Colln.*).—L. Richardson.

Diagnosis.—Shell small, curved, with extremely-fine transverse lineæ (visible only with the aid of a lens); section circular or slightly elliptical; posterior end noticeably acuminate, with a diameter of 0·25 mm., and having (for the length of the shell, 3 to 6 mm.) a broad anterior end—the diameter being three times as great as that of the posterior end. Length of holotype = 3·9 millimetres.

Remarks.—On a tablet in the Sedgwick Museum, Cambridge, are ten fossils from the 'Lower Lias, Worcestershire, H. E. S [trickland].' One of these is a *Ditrupa*, another *D.* cf. *elongatum*, Münster, and the remainder probably *D. acutum*. Four of the specimens referred to *Dentalium acutum* are represented (twice natural size) by figs. 11 *a*, *b*, *c*, & *d*, Pl. XLV. Certainly the specimens represented by figs. 11 *a* & *b* belong to this species; and (although I am not absolutely sure) most probably those represented by 11 *c* & *d* do also. Some weeks after the above were examined, I collected from the clay exposed in a railway-cutting near Gotherington, three examples of a form precisely similar to the predominant type in the series collected by Strickland.

Dentalium parvulum, described on p. 585, is the most closely-related form, but is usually double the length of the present species, attenuates more regularly, and even in the ephebic stage does not show the markedly-acuminate posterior end. *Dentalium minimum* (p. 582) is much more slender, more erect, and cannot be confused with *D. acutum*.

DENTALIUM ANGULATUM, Buckman.

T.d. 1844. James Buckman, Murchison's 'Outline of the Geology of Cheltenham' new ed. p. 101.
T.f. None.

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[1] The letters in parentheses are the abbreviations which will be employed in this paper; and, for fuller information concerning the use of these and others, the reader is referred to Mr. S. S. Buckman's papers in 'Science' n. s. vol. xxi (1905) pp. 899–901, and Ann. & Mag. Nat. Hist. ser. 7, vol. xvi (1905) p. 102. It has been suggested to me that the abbreviation for 'Collection,' namely *Colln.*, is preferable to *Coll.*, since the latter might mean 'collected by.'

T.l. 'Alderton, Dumbleton, and Stanway Hills [Gloucestershire].'
H. 'Lias Marlstone.' [Pliensbachian.]
η. [*spinati* or *margaritati*, probably the former.]
Colln. [Not known.]
Non 1875. *D. angulatum*, R. Tate, Quart. Journ. Geol. Soc. vol. xxxi, p. 508.
Nec 1877. *D. angulatum*, T. Beesley, Proc. Warwickshire Nat. & Arch. F. C. p. 16.

Protolog.—'Shell obtusely quadrangular, slightly curved, somewhat rugose, with transverse lines, about 1¾ inch in length.'

Remarks.—Not one of the proterotypes can be found. I cannot help feeling a little sceptical as to whether the fossil has been correctly diagnosed; but, supposing that it has been, it is impossible to refer to this species, as Ralph Tate has done, the little shell from the *striatum*-beds.

DENTALIUM ELONGATUM, Münster. (Pl. XLV, figs. 17 & 18.)

T.d. 1841. Münster (in Goldfuss), 'Petrefacta Germaniæ' pt. iii, p. 2.
T.f. *Ibid.*, pl. clxvi, fig. 5.
T.l. Banz.
H. 'E formatione Lias dicta.' [Pliensbachian ?]
η. ——
Colln. ——

Dentalium elongatum, Oppel, 1856–58, 'Die Juraformation' p. 390; Terquem & Piette, 1865, 'Le Lias Inférieur de l'Est de la France' Mém. Soc. Géol. France, ser. 2, vol. viii, p. 67; Giebel, 1866, 'Repertorium zu Goldfuss' Petrefakten Deutschlands' p. 88; Dumortier, 1869, Études Paléont. &c. pt. iii, 'Lias Moyen,' p. 336; R. Tate, 1870, Quart. Journ. Geol. Soc. vol. xxvi, p. 398; (*D. gracile*, Moore), R. Tate, 1875, *ibid.* vol. xxxi, p. 504; R. Tate, 1876, 'The Yorkshire Lias' p. 332 & pl. ix, fig. 28; T. Beesley, 1877, Proc. Geol. Assoc. vol. v, p. 183; E. A. Walford, 1879, Proc. Warwickshire Nat. & Arch. F.C. p. 21 ('Fish-bed'); Wright, 1879, 'Monogr. Lias Ammonites Brit. Isles' Pal. Soc. pp. 69, 107; Slatter (in Wright) 1882, *ibid.* p. 375; Richardson, 1904, 'Handbook to the Geology of Cheltenham' p. 219 & pl. xiv, fig. 7.

Syn. 1836. *Dentalium cylindricum*, F. A. Rœmer [*non* Sowerby], 'Die Versteinerungen des Norddeutschen Oolithen-gebirges' p. 134.
? 1852. *D. filicauda*, Quenstedt, 'Handbuch der Petrefaktenkunde' p. 443 & pl. xxxv, fig. 18.
? 1858. *D. filicauda opalina*, Quenstedt, 'Der Jura' p. 328 & pl. xliv, fig. 16.
1864. *D. filicauda*, Seebach, 'Der Hannoversche Jura' p. 131.
1865. *D. elongatum = filicauda*, Brauns, 'Die Stratigraphie & Paläontographie des südöstlichen Theiles der Hilsmulde, &c.' Palæontographica, vol. xiii, p. 113.
1867. *D. gracile*, Moore, Proc. Somerset Arch. & Nat. Hist. Soc. vol. xiii, p. 202 & pl. v, fig. 23; see also p. 161.
1877. *D. gracile*, Smithe, Proc. Cotteswold Nat. F. C. vol. vi, p. 372.
1877. *D. gracile*, Slatter (in Beesley), Proc. Geol. Assoc. vol. v, p. 183.
1879. *D. gracile* (*D. elongatum*, Münster), Walford, Proc. Warwickshire Nat. & Arch. F. C. p. 18 (*acuti* hemera).
1904. *Dentalium* sp., Richardson, 'Handbook to the Geology of Cheltenham' p. 219.

Protolog.—'*Dentalium* testa crassiuscula tereti gracili subarcuata lævi.—E montibus Bambergicis. M.M.'

Remarks.—This common *Dentalium* has the most extensive range in time of all the Liassic species. From *Dentalium etalense* it differs mainly in the degree of curvature: *D. etalense* being regularly curved from end to end, whereas *D. elongatum* is usually the most strongly curved in the posterior part and nearly straight in the anterior. The smooth *Dentalia* are very difficult to identify, and matters are

complicated by the fact that, associated with indubitable specimens of the species under consideration, are forms differing therefrom either in being very much more erect, or in being very considerably thinner but equally straight. It does not seem desirable to separate these forms, at any rate for the present, and provisionally they may be regarded as varieties, and *D. elongatum* as the collective species.

Moore, however, named the form which was erect and of about the same size as *Dentalium elongatum*, *D. gracile*; and it may possibly be convenient to record such specimens under this name. In Pl. XLV, fig. 19 *a*, will be found a figure of Moore's holotype. The specimen came from the *armatum*-beds of Camerton, and is now preserved in the Bath Museum. Fig. 19 *b* shows the same enlarged, and 19 *c* is a transverse section of the anterior end. Fig. 18 represents a specimen referable to Moore's 'species,' obtained from the *armatum*-zone exposed in the approach-cutting to the Hunting-Butts tunnel (G.W.R.), near Cheltenham.

The very slender erect form has been noticed at several localities, and is possibly the forerunner of *Dentalium filicauda opalina*, Quenstedt. It is a little doubtful whether Quenstedt's species should be associated with *Dentalium elongatum*, Münster. He said that it was smooth and similarly constructed; but remarked that 'at the top the tube narrows to the thinness of a human hair'; and continued,

'the *Dentalia* in Lias α pag. 55 do not become so thin as this, although they have just the same appearance. This genus plays an important part for the first time in the *opalinus*-nodules, and continues with the same species up to Beta.' ('Der Jura' p. 329.)

This extreme tenuity is not one of the characteristics of *Dentalium elongatum*, Münster, and most probably Quenstedt's form is distinct therefrom.

The shell which Oppel identified with *D. elongatum* came from deposits between the zones of *Ammonites torulosus* and *A. opalinus*, and along with *D. filicauda opalina*, Quenstedt, can only be provisionally associated with Münster's species. *Dentalium Parkinsoni*, Quenstedt, from the Middle Lias (his Lias δ), is probably the same as *D. elongatum*.

In the zone of *Belemnites acutus* at Renwez, Etales, and Aiglemont, Terquem & Piette found *D. elongatum* very abundant, and attaining a length of from 30 to 40 millimetres.

Dumortier's specimens from the Infra-Lias, which he referred to this species, are most probably *Dentalium etalense*, Terq. & Piette; but those from the *margaritatus*-beds of Mont Ceindre are doubtless correctly named.

Ralph Tate recorded this scaphopod from the *margaritatus*-, *spinatus*-, *annulatus*-, and *jurensis*-beds of Yorkshire. The fragment which he figured is preserved in the Museum of Practical Geology [7997], and shows well the fine 'concentric striæ.'

I have examined species of *Dentalium elongatum* from the beds

and localities mentioned in the appended list, the dates of the various deposits being stated in hemeral terms :—

spinati, Alderton Hill, Gloucestershire ; *margaritati*, Lightpill clay-pit, Stroud ; *capricornus*, Robins' Wood Hill, near Gloucester, Pilford (or Pilley) clay-pit, Cheltenham ; *striati*, Battledown clay-pit (Messrs. Webb Bros.), Cheltenham, & railway-cutting, 'Dixton West,' Gotherington, near Cheltenham (very slender and erect form) ; *Valdani* (about), Leckhampton, Cheltenham (H. B. Holl Colln., Nat. Hist. Mus.)[1] ; *Valdani*, Leckhampton Station clay-pit, Cheltenham,[2] railway-cuttings near Didbrook & Hailes (near Cheltenham) ; *Jamesoni*, Tyning's Quarry, Radstock, *armati-Jamesoni*,[3] railway-cutting, Toddington (near Cheltenham), *armati* (& *Jamesoni* ?),[4] railway-cutting, Aston Magna, near Moreton-in-the-Marsh (Slatter Colln., Nat. Hist. Mus. ; and specimens collected by G. E. Gavey and deposited in the Sedgwick Museum, Cambridge) ; *Jamesoni* (probably), Bishop's-Cleeve Station, near Cheltenham ; *armati*, Aston Magna clay-pit, Folly-Lane clay-pit, Cheltenham, approach to Hunting-Butts tunnel (southern end), near Cheltenham (Pl. XLV, fig. 18), railway-cutting under St. George's Road, Cheltenham ; *oxynoti-armati*, railway-cutting near Stanton-Fields Farm, Stanton (Glos.), Gasworks, Gloucester[5] ; *stellaris* (or *oxynoti-armati* ?),[6] Bredon [railway-cutting ?], Worcestershire (Strickland Colln., Sedgwick Museum, Cambridge) ; *Turneri*, Honeybourne clay-pit, near Evesham (very slender, erect variety : Slatter Colln., Nat. Hist. Mus.) ; *Birchi*, well-excavation, Down Hatherley, near Cheltenham ; [*Birchi*], Shekel's brickyard, Pebworth, near Honeybourne[7] (R. F. Tomes Colln., Nat.

[1, 2] The clay-pits where Holl collected his specimens were no doubt those to which Ralph Tate referred as the 'Leckhampton Road clay-pits, Cheltenham.' Tate published his paper 'On the Palæontology of the Junction-Beds of the Lower & Middle Lias in Gloucestershire' in the Quarterly Journal of the Geological Society for 1870, and wrote :—'At Cheltenham the zone of *Ammonites Jamesoni* is exposed in the clay-pits by the Leckhampton Road . . .' (*op. cit.* p. 396). Mr. J. W. Gray, F.G.S., tells me that between 1866 and 1876 the principal clay-pits near the Leckhampton Road were situated in the immediate neighbourhood of the present Leckhampton Station. There were two pits here adjoining : the one nearest the Leckhampton Road being called 'Winning's pit,' and the other 'Thackwell's.' The latter was by far the more important of the two, and is the one to which I have referred in this paper as the 'Leckhampton-Station clay-pit.' When the Great Western Railway was constructed advantage was taken of the position of the pits, and the line of railway was taken through them. The present pit is in the *Valdani*-beds, but some of the fossils collected by Mr. Gray corroborate Tate's statement that deposits higher than his *Jamesoni*-zone, namely the *Henleyi*-(or *striatum*-) beds, were exposed. In the clays of Thackwell's Pit Mr. Gray noticed the skeleton of a fine *Ichthyosaurus*.

[3] The greater bulk of the clay exposed in this cutting was of *armati* hemera, but above came a thin zone, crowded with species of *Zeilleria*, *Rhynchonella*, and gasteropods, which is most probably of *Jamesoni* date.

[4] Gavey recorded in his list of fossils from here, definitely, only *Ammonites armatus* ; but several authors have described fossils from the same locality as coming from the *Jamesoni*-beds. The clay-banks of the cutting are now covered with grass, but it seems to have been in a deposit similar to that exposed at Toddington.

[5] The fossils from the gas-works at Gloucester were obtained from clay (containing ammonites indicative of a deposit made during *oxynoti*, *raricostati*, and *armati* hemeræ) dug out to allow for the laying of the foundations of a gas-holder.

[6] The clay seen in the side of the cutting by the goods-siding is of *stellaris* hemera ; but Strickland found ammonites indicative of later hemeræ, farther up the line to the north, in the direction of Eckington.

[7] Mr. E. Talbot Paris, who visited the locality at my request, found the pit quite overgrown.

Hist. Mus.), [*Birchi ?*] Besford [clay-pit near], Worcestershire [1] (Slatter Colln., Nat. Hist. Mus.); *rotiformis*, Bengeworth clay-pit, Evesham; [*rotiformis ?*], Aldington Leys, near Evesham (Slatter Colln., Nat. Hist. Mus.); [*marmoreæ*], Island Magee (Tate Colln., Mus. Practical Geology, Jermyn Street).

DENTALIUM ETALENSE, Terquem & Piette. (Pl. XLV, figs. 14 & 15 *a–b*.)

T.d. 1865. 'Le Lias Inférieur de l'Est de la France' Mém. Soc. Géol. France, ser. 2, vol. viii, p. 67.
T.f. *Ibid.* pl. ii, fig. 43.
T.l. Saint-Menge.
H. 'Calcaire à *A. angulatus*.' [Hettangian.]
η. [*marmoreæ*.]
Colln. ——

Dentalium etalense, Brauns, 1871, 'Der Untere Jura' pp. 288–89; Tate, *pars*, 1876, 'The Yorkshire Lias' p. 332 & pl. ix, fig. 13; Richardson, 1905, Quart. Journ. Geol. Soc. vol. lxi, p. 394.

Syn. ? 1858. *Dentalium*, Quenstedt, 'Der Jura' pp. 55–56 & pl. v, fig. 14 (8); also p. 60 & pl. vi, fig. 8.
1864. *D. elongatum*, Dumortier, 'Etudes Paléont. &c.' pt. i, 'Infra-Lias' pp. 143–44.
1870. *D.* cf. *Andleri*, Emerson, 'Die Liasmulde von Markoldendorf bei Einbeck' Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxii, p. 309.

Remarks.—Terquem & Piette state that the length of their species is 24 millimetres, and the breadth 2; that it differs from *Dentalium elongatum* in being more slender, more curved, and by the absence of transverse lineæ; and from *D. compressum*, d'Orbigny, by measuring twice the length and having a much thicker test. The holotype came from the *angulata*-beds of Saint-Menge, but it is very rare there. On Pl. XLV will be found a copy of the protograph, and also (fig. 15) a representation of a specimen from the *angulata*-beds of Stout's Hill, near Bitton (near Bath), preserved in the Moore Collection at Bath.[2]

With *Dentalium etalense*, Brauns identified a number of specimens from several horizons. He regarded *Dentalium compressum*, Terquem, as being synonymous with this species (see p. 588); he was certain that this was the case with *D.* cf. *Andleri*, Emerson; but was not sure that he was correct in associating Oppel's *D. Andleri* with the same. Tate thought that Oppel's species was the same as his *Dentalium Portlocki*.

In 1876, Tate came to regard his species *Dentalium Portlocki* as synonymous with *D. etalense*, Terq. & Piette. Probably most, if not all, of the Yorkshire specimens recorded under this name by Tate do really belong to Terquem & Piette's species, because they are all *angulata*- and *Bucklandi*-zone fossils; but the Irish specimens, and some recorded by him from other places as well, are *Dentalium minimum*. The largest Yorkshire example as yet obtained measures

[1] This clay-pit is also abandoned, and nearly overgrown. The only pit now open in the neighbourhood of Pershore is that west of Pigeon House, Drake's Broughton, that at the Atlas Works at Pershore Station being likewise disused. See Mem. Geol. Surv. 'The Jurassic Rocks of Britain' vol. iii (1893) 'The Lias' pp. 148, 149.

[2] Proc. Bath Nat. Hist. & Antiq. F. C. vol. vii (1892–93) p. 286.

1·2 inches in length. It is the one figured in 'The Yorkshire Lias' (pl. ix, fig. 13), and is now at the Museum of Practical Geology, Jermyn Street [7998]. It shows well the characteristic features of the species, and is an *angulata*-bed fossil, occurring in dark shale with many shell-fragments. *Dentalium etalense* certainly attains its maximum in the *angulata*-beds and rarely occurs above or below.

DENTALIUM GIGANTEUM, Phillips. (Pl. XLV, figs. 16*a*–16*b* & text-fig. 1, p. 580.)

T.d. 1876. Tate, 'The Yorkshire Lias' p. 331.
T.f. 1829. Phillips, 'The Geology of the Yorkshire Coast' pl. xiv, fig. 8.
T.l. Robin Hood's Bay (Yorkshire).
H. 'Middle Lias.' [Pliensbachian.]
η. [*margaritati.*]
Colln. York Museum.

Dentalium giganteum, Morris, 1843, 'A Catalogue of British Fossils' 1st ed., p. 143; Gavey, 1853, Quart. Journ. Geol. Soc. vol. ix, p. 34; Oppel, 1856, 'Die Juraformation Englands, Frankreichs & des südwestlichen Deutschlands' p. 173; Wright, 1858, Quart. Journ. Geol. Soc. vol. xiv, p. 26; ? Terquem & Piette, *pars*, 1865, 'Le Lias Inférieur de l'Est de la France' Mém. Soc. Géol. France, ser. 2, vol. viii, pp. 67–68; Tate, 1876, 'The Yorkshire Lias' pp. 331–332 & pl. ix, fig. 10; Beesley, 1877, Proc. Geol. Assoc. vol. v, p. 183.

Syn. 1822. *Dentalium entalis*, Young & Bird, 'Geological Survey of the Yorkshire Coast' p. 244 & pl. xi, fig. 13.
1828. *Ibid.* 2nd ed. p. 250 & pl. xi, fig. 20.
1854. *D. entale*, Morris, 'Catalogue of Brit. Fossils' 2nd ed. p. 246.
Non 1904. *D. giganteum*, Richardson, 'Handbook to the Geology of Cheltenham' p. 219.

Diagnosis.—Shell distinguished by its great length, being often 3 inches long and a quarter of an inch in diameter at the aperture, slightly curved, thick, smooth, cylindrical, but somewhat quadrangular, and slightly sulcated towards the apex.

Remarks.—This well-known Yorkshire fossil was first figured by Young & Bird, and described by them as 'belonging to the species *D. entalis*, or one nearly the same,' but not being Linné's species was figured by Phillips as *Dentalium giganteum*. His figure, however, is not at all satisfactory, though a good one was furnished by Tate & Blake in their 'Yorkshire Lias,' and a copy of this is given on Pl. XLV, fig. 16*a*, with the addition of a transverse section (fig. 16*b*). The transverse section is sometimes circular, sometimes quadrangular. Tate (*op. cit.* p. 332) remarked that

'the species was gregarious in what is now called Cleveland; myriads of them may be seen covering the upper surfaces of some of the sandstones situated near to the base of the Zone of *Ammonites margaritatus* at Hawsker, Staithes, Rockcliff, Hummersea, Huntcliff, and Coatham Scars, on the coast, and inland at Hutton, near Guisboro', and in Danbydale. It is found on the same horizon in Lorraine and in North Germany.'

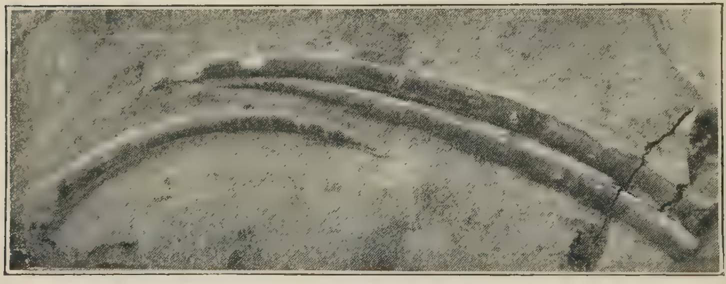
No description of the species was furnished by Phillips. The diagnosis here given was taken from Tate's in 'The Yorkshire Lias,' some slight alterations being made.

In the Geological Society's Museum at Burlington House there is a piece of rock containing a number of worn fragments embedded in a brown and grey earthy limestone (of *margaritati* hemera

presumably), and bearing the legend '*Dentalium giganteum*, Phill., Middle Lias, Huntcliff, Yorkshire. R. Murchison, Esq., F.G.S.' [4338].

In the Moore Collection at Bath are several fine specimens in rock (*margaritati* hemera) from the 'Middle Lias, Cleveland, Yorkshire.' These specimens are shown in the appended text-figure 1. In the memoir on 'The Lias of England & Wales (Yorkshire excepted),' published by the Geological Survey (1893, p. 352), *Dentalium giganteum* is noted from Somerset, Gloucestershire, Warwickshire, and Yorkshire; from the first-named county presumably on Moore's

Fig. 1.—*Dentalium giganteum*, Phillips. *(Natural size.)*



[From the Moore Collection, Bath Museum. Photographed by Major E. F. Becher.]

authority. The record from the Middle Lias of Camerton requires confirmation, for although Moore stated that it was there associated with *D. gracile*, Moore,[1] he does not mention it in his list of fossils from the 'Middle Lias of the Camerton and Radstock Districts' on page 161 of that essay; neither does Tate mention its occurrence in his paper on the same district.[2] The record of this *Dentalium* from the Marlstone of Ilminster is probably correct. Mr. T. Beesley has recorded it from the *capricornus*- and *margaritatus*-beds of the Chipping-Norton railway-tunnel.

Some better-preserved fragments of the fossil, thought to be the infilling of the tube of *D. giganteum*, Phillips, from the *capricornus*-zone of Robins' Wood Hill, near Gloucester, and entered under that name in my 'Handbook to the Geology of Cheltenham' 1904, p. 219, suggest that they probably filled in the cylindrical cavity of some large tubicolous annelid; but, until more material has been obtained, this must remain an open question.

Those specimens of Terquem & Piette's *Dentalium giganteum*, which are *angulata*-bed fossils, will be found discussed as *Dentalium Terquemi* on p. 589; while those from the *Plicatula-spinosa* Zone

[1] Proc. Somerset Arch. & Nat. Hist. Soc. vol. xiii (1865–67) p. 202.
[2] Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 504.

are provisionally regarded as correctly identified with *D. giganteum*, Phillips.

Except in Yorkshire, this scaphopod does not appear to be at all common; indeed, I have examined specimens only from that county. *Dentalium giganteum*, I think, lived only during the *margaritati* hemera.

DENTALIUM HEXAGONALE, sp. nov. (Pl. XLV, figs. 1 *a*–1 *c*.)

T.l. Gasworks, Gloucester.
H. Sinemurian-Pliensbachian.
η. [*oxynoti-armati.*]
Colln. L. Richardson.

Diagnosis.—Shell small, curved; transverse section circular interiorly, hexagonal exteriorly; surface-ornamentation consisting of numerous, closely-set, regular, fine transverse lineæ. Dorsal side broad, very slightly convex towards the anterior end. The sides converge towards the ventral surface, but while slightly inflated near their junction with the dorsal side, give rise to sharp angular keels at their junction with the ventral side, which also becomes slightly convex near the anterior end.

Remarks.—The transverse section of this scaphopod is the characteristic feature, and easily distinguishes it from all other Liassic forms. In the gerontic stage, however, the section of the anterior end is very similar to that of *D. subtrigonale* in the same stage; but the hexagonal form is otherwise a very constant character. The records are:—*armati-Jamesoni*, railway-cutting, Toddington, near Winchcomb (near Cheltenham); *armati* (and *Jamesoni?*), railway-cutting, near Aston Magna, near Moreton-in-the-Marsh (Slatter Colln., Nat. Hist. Mus., identified by Slatter with *D. angulatum*, J. Buckman); *oxynoti-armati*, Gasworks, Gloucester.

DENTALIUM LIASSICUM, Moore. (Pl. XLV, figs. 6 *a*–6 *c*.)

T.d. 1865–67. Proc. Somerset Arch. & Nat. Hist. Soc. vol. xiii, p. 202.
T.f. *Ibid.* pl. v, fig. 24.
T.l. Camerton [near Radstock, Somerset].
H. 'Middle Lias.' [Pliensbachian.]
η. [*armati.*]
Colln. Moore, Bath Museum.

Dentalium liassicum, Tate, 1876, 'The Yorkshire Lias' p. 333; Walford, 1879, Proc. Warwickshire Nat. & Arch. F. C. p. 18; Thompson, 1888–89, 'Middle Lias of Northamptonshire' p. 29.

Protolog.—'Shell slightly incurved and tapering, thick, outer surface ornamented with about twenty-four longitudinal ridges at rather irregular distances, within which are numerous slightly-oblique annular lines of growth; aperture circular.'

Length of holotype (fragment), between 5 & 6 millimetres.

Remarks.—Of this rare *Dentalium*, which is easily distinguished from the other Jurassic species by its longitudinal ornament, Charles Moore possessed but one specimen, 'which has lost its apical portion.' This is the specimen in the Bath Museum. The 'annular

lines of growth' are very faint, but can be detected with the aid of a lens.

Judging from the matrix, the holotype came from the *armatum*-zone; but the species has also been recorded from the Upper Lias (or Toarcian) of several localities. Mr. J. W. Tutcher, who kindly examined for me the collection which the late Edward Wilson kept at his private residence, with a view to seeing whether it contained any Liassic scaphopods, writes:

'There are only three small boxes containing *Dentalia*, two of which are labelled "*Dentalium liassicum*, U[pper] L[ias], Lincoln."'

Presuming that the Toarcian specimens are correctly named, the records of this species are as follows:—*Dentalium liassicum*, Moore, 'Middle Lias' [*armati*], Camerton (Somerset); 'Zone of *Am. annulatus*,' Hob Hill, near Saltburn (Yorkshire); 'Transition-bed' [*acuti*], Chipping Warden; 'Lower Cephalopoda-Bed,' Upper Lias [*falciferi*], Northamptonshire; 'Upper Lias,' Lincoln.

Dentalium limatulum, Tate. (Text-fig. 2.)

T.d. 1870. Tate, Quart. Journ. Geol. Soc. vol. xxvi, p. 402.
T.f. *Ibid.* pl. xxvi, fig. 1. [But not the transverse section; for that see the appended text-figure.]
T.l. Cloverly (Shropshire).
H. 'Zone of *Belemnites acutus*.'
Colln. R. I. Murchison, Geological Society, Burlington House [No. 4441*].[1]

Fig. 2.—*Sketch of transverse section of the anterior end of* Dentalium limatulum, *Tate, to show the flat latero-dorsal portion of the test.*

[Magnified about 6 diameters.]

Protolog.—'Shell small, moderately thick, obtusely triangular, slightly curved, ornamented with numerous, closely-set, regular, slightly-oblique and acute costæ [that is, transverse lines]. Dimension: length (*teste* Tate) = 0·5 inch.'

Remarks.—Unfortunately, only a fragment of the holotype, 3 millimetres in length, is preserved. A sketch of the transverse section of this is appended (fig. 2), but it will be seen to differ materially from Tate's. The flattening of the left-hand side in the half adjoining the dorsal side is not due to crushing, as can be seen from the structure of the shell and the regular circularity of the aperture. The specimen is unique, but not abnormal, and is distinct from those forms found in the Lower Lias of Redcar which Tate associated with it (see p. 587).

Dentalium minimum, Strickland-Buckman. (Pl. XLV, figs. 13*a*–13*c*.)

T.d. 1844. J. Buckman, in Murchison's 'Outline of the Geology of Cheltenham' new ed. p. 101.
T.f. None.

[1] This holotype was omitted from the 'List of Types & Figured Specimens in the Collection of the Geological Society of London' by C. D. Sherborn & J. F. Blake (London, 1902).

T.l. 'Cracombe.' [Craycombe, near Evesham.]
H. Lower Lias. [Hettangian.]
η. [*marmoreæ.*]
Colln. H. E. Strickland. [Cannot be found.]

Dentalium minimum, Tate, *pars*, 1863–64, Quart. Journ. Geol. Soc. vol. xx, p. 111.

Syn. 1843. *Dentalium tenue*, Portlock, 'Report on the Geology of Londonderry, &c.' p. 118 (*non* Goldfuss, 1841).
1856. *D. Andleri*, Oppel, 'Die Juraformation' p. 93 (probably).
1867. *D. tenue*, Tate, Quart. Journ. Geol. Soc. vol. xxiii, p. 311.
1870. *D. Portlocki*, Tate, Proc. Belfast Nat. F. C., App. i, p. 17 & pl. i, fig. 15.
? 1876. *D. etalense*, Tate, *pars*, 'The Yorkshire Lias' p. 332.

Protolog.—'Shell cylindrical, smooth, very minute, slightly curved, about a quarter of an inch in length.'

Remarks.—This description also represents the main features of *Dentalium Portlocki*, Tate, but it may be added that Tate's specimen tapers regularly from the anterior to the posterior end, has a circular section, and measures about 4·5 mm. in length, 0·5 mm. across the section of the anterior end, and 0·25 millimetre across the posterior end.

In 1843 Portlock obtained fragments of a small *Dentalium*, concerning which he gave the following information :—

'*Dentalium tenue* (Portlock).—Aghanloo, Ballymaglin, and Ballycarton. Fragments of this delicate *Dentalium* occur, with *Modiola minima*, in a fine calcareous grit; the longest, ·4 of an inch, is about ·04 of an inch in diameter at the largest end, and tapers to a fine point. It is very slightly curved. Magilligan, Craig, and Gortmore; hard calcareous grit.' ('Report on the Geology of Londonderry, &c.' p. 118.)

In the following year James Buckman published the very brief description which has already been given (protolog), of an equally-small scaphopod procured from beds of about the same age at Craycombe, near Evesham, and assigned to the fossil Strickland's manuscript name of *Dentalium minimum*.

Ralph Tate subsequently pointed out that *Dentalium minimum*, Strickland-Buckman, was identical with Portlock's *D. tenue*.[1] As, however, the specific name *D. tenue* was preoccupied by a *Dentalium* figured by Goldfuss (to which the specimen under consideration was not referable), Tate retained Strickland's denomination, abandoning Portlock's name. He says :—

'*D. minimum* I have found pretty frequently on the west shore of Island Magee, Co. Antrim. I have also obtained it in great abundance in the Lower Lias clay-pits off the Leckhampton Road, Cheltenham. The Irish examples are less curved and elongated and more slender than the Cheltenham forms.'

For some reason, however, in 1867, Tate revived Portlock's name of *D. tenue*[2] for the small shell from the *angulata*-beds. This can be seen from his published work, and presumably at this time he also regarded the Cheltenham specimens as belonging to the same

[1] Quart. Journ. Geol. Soc. vol. xx (1864) p. 111.
[2] *Ibid.* vol. xxiii (1867) p. 311.

species, because in the Natural History Museum there is a tablet (G. 6394) with this information on the back:

'*Dentalium tenue*, Portlock. Lower Lias Shales, Leckhampton Road [Cheltenham]. R. T.'

At a later period Tate regarded *Dentalium tenue* and *D. minimum* as distinct. He apparently retained Portlock's name for the specimens from the *angulata*-beds, and Strickland's for those from the *Jamesoni*-zone (*sic*) of Cheltenham.[1] The paper in the Quarterly Journal was published in March, 1870. In September of the same year there appeared, in the Proceedings of the Belfast Naturalists' Field-Club, a communication wherein the name of the *angulata*-bed fossil was changed from *Dentalium tenue* to *D. Portlocki*. The specimen to which this name was applied is in the Museum of Practical Geology at Jermyn Street [7999], and there are two other examples of what appear to be a similar form in the same collection.

Thus, at the close of the year 1870, Tate regarded the scaphopod from the *Jamesoni*-zone (*sic*) of Cheltenham as *D. minimum*, Strickland, and that from the *angulata*-beds as *D. Portlocki*, Tate.

Whether Tate ever discovered that the true *Dentalium minimum* from the *angulata*-beds was distinct from that which he was at this time identifying with it from the *Jamesoni*-zone (*sic*) of Cheltenham, will never be definitely known; but a hint that he did so may be gathered from the legend on a tablet in the possession of the Geological Society, which reads:

'*Dentalium parvulum*, Buckman. Middle Lias, Leckhampton Road Clay-Pits, Cheltenham. R. Tate, Esq., F.G.S.'

When he arrived at this conclusion, namely, that the shell from the *angulata*-beds was distinct from that from the '*Jamesoni*-zone,' and saw fit to employ for the latter a manuscript name apparently in use by James Buckman, it is impossible to say; but that Buckman considered the forms distinct is obvious.

In 1876 Tate considered his species *Dentalium Portlocki* as synonymous with *D. etalense* of Terquem & Piette.[2]

I have been unable to discover the whereabouts of any types of *Dentalium minimum*, Strickland-Buckman. There are no specimens answering the description of its author in the Sedgwick Museum, Cambridge; the Rev. J. B. McClellan, Principal of the Royal Agricultural College, Cirencester, writes to me that there are no examples of Liassic Dentaliidæ in the museum of that Institution; and Mr. S. S. Buckman does not know where the type may be.

The holotype of Tate's *Dentalium Portlocki*, however, is preserved at the Museum of Practical Geology [7999]. Since no proterotypes of *Dentalium minimum* can be found and no topotypes can be obtained, and since *D. Portlocki* and *D. minimum* certainly seem identical, I have taken for the standard reference Tate's figure of *D. Portlocki*. Thus the holotype of *D. Portlocki* becomes the neotype of *D. minimum*, Strickland-Buckman.

[1] Quart. Journ. Geol. Soc. vol. xxvi (1870) p. 398.

[2] 'The Yorkshire Lias' 1876, p. 332, and specimens in the Museum of Practical Geology.

DENTALIUM OBLONGUM, sp. nov. (Pl. XLV, figs. 3 *a*–3 *d*.)

T.l. Railway-cutting (G.W.R.), Dixton West, near Gotherington, near Cheltenham.
H. Pliensbachian.
η. striati.
Colln. L. Richardson.

Syn. 1875. *Dentalium angulatum*, Tate (*non* Buckman), Quart. Journ. Geol. Soc. vol. xxxi, p. 508.
? 1877. *D. angulatum*, Beesley, Proc. Warwickshire Nat. & Arch. F. C. p. 16.

Diagnosis.—Shell small, slightly curved, transverse section of the anterior end usually oblong exteriorly and interiorly, with acute prominent ridges at the junction of the sides with the dorsal margin: transverse section of the posterior end quadrangular exteriorly, with prominent ridges at the angles, between which are concave regions, circular interiorly. The surface-ornamentation consists of numerous, closely-set, fine, transverse lineæ. Length of holotype = 5·5 millimetres.

Remarks.—This scaphopod was associated in considerable numbers with *Dentalium acutum* in the clay exposed in the railway-cutting near Gotherington which I have called 'Dixton West.' It also occurs not infrequently in the shelly masses of limestone of *striati* hemera found at the Battledown Brickworks (Messrs. Webb, Bros.), Cheltenham. Tate obtained it from the same horizon ('Yellow Lias') at 'Hewlett's Hill, Cheltenham,' where the *striatum*-beds were formerly well exposed.[1]

DENTALIUM PARVULUM (J. Buckman, MS.), sp nov. (Pl. XLV, figs. 9 *a*–9 *c* & 12 *a*–12 *b*.)

T.l. Leckhampton Station clay-pit, Cheltenham.
H. Pliensbachian.
η. Valdani.
Colln. L. Richardson.

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[1] This clay-pit at the Cemetery-Road Brickworks (called on the 6-inch map Harp Hill') is frequently spoken of as 'Shackel's Pike.' Clay has been worked here for over a century. In Buckman & Strickland's revised edition of Murchison's 'Outline of the Geology of Cheltenham' (Cheltenham, 1844; London, 1845), many fossils are recorded from the 'L[ias] S[hale], Yellow Lias, Hewlett's Road,' and occasionally in the same work this description occurs, with the addition of the words 'foot of Battledown.' When Sir Roderick wrote his little book in 1834 (and ten years later when Buckman and Strickland brought out the above-mentioned revised edition) there was a clay-pit, where the chimney-stack of the Battledown Brickworks now stands, known as 'Coltham-field.' The upper portion of the *Valdani* and the lower portion of the *striatum*-beds would have been the deposit worked there then. Now, however, this particular pit is filled in, and the hill is being worked into, and increasingly-higher beds are being exposed. At the present time (April, 1906) the yellow argillaceous and ferruginous nodules of the *striatum*-beds constitute the newest deposit seen. On the other hand, at the Cemetery-Road pit they have been working down the hillside. The late Prof. J. F. Blake told me that he recollected collecting here from the *capricornus*-zone, and, as can easily be gathered from the writings of James Buckman, the 'Yellow Lias' (*striati*) must also have been admirably exposed. Now the main excavation at the Cemetery-Road pit is in the *Valdani*-zone, while only occasional tumbled nodules and disinterred fossils, indicative of a deposit of *striati* hemera, are seen on the very broken ground above.

Syn. 1863–64. *Dentalium minimum*, Tate, *pars* [the specimens from Cheltenham], Quart. Journ. Geol. Soc. vol. xx, p. 111.
1870. *D. minimum*, Tate, *ibid.* vol. xxvi, p. 398.
1877. *D. minimum*, Beesley, Proc. Geol. Assoc. vol. v, p. 183.
1877. *D. minimum*, Beesley, Proc. Warwickshire Nat. & Arch. F. C. p. 16.
1879. *D. minimum*, Wright, 'Monogr. Lias Amm.' Pal. Soc. p. 69.
1882. *D. minimum*, Slatter (in Wright), *ibid.* p. 375.
1904. *D.* aff. *minimum*, Richardson, 'Handbook to the Geology of Cheltenham' p. 219.

Diagnosis.—Shell small, much curved, thin unworn specimens usually exhibiting numerous, extremely-fine, closely-set, transverse lineæ; section circular or elliptical; the shell tapers, especially in immature forms, rapidly from the thicker anterior end to a fine point.

Remarks.—To the history of this species recorded when dealing with *Dentalium minimum* (pp. 582–584) it remains to be added that, in the collection of the Geological Society of London, are four specimens mounted on a tablet bearing the words

'*Dentalium parvulum*, Buckman. Middle Lias, Leckhampton Road Clay-Pits, Cheltenham. R. Tate, Esq., F.G.S.'

No description of this species has been published, so far as I know, nor has any figure appeared.

I think that there can be very little doubt that James Buckman noticed that this form was distinct from *Dentalium minimum*, and employed the manuscript name of *D. parvulum* for his own convenience; and, when Tate became cognizant of the fact, he agreed with Buckman and recognized his name. At all events, the existence of this tablet of specimens is useful, in that it hints at an idea, never definitely expressed, that the Cheltenham '*D. minimum*' was distinct from the *angulata*-bed fossil of the same name.

For some time, I was disposed to think that the forms included in this paper under the name of *Dentalium parvulum* represented three distinct species. The specimens of this *Dentalium* from the *Valdani*-beds have a section becoming slightly elliptical at times, but when this is the case the major axis of the incipient ellipse runs diagonally from (so to speak) the left-hand top part of the section to the right-hand bottom part, and the principal thickening of the test occurs on the dorsal side. Another slightly-different form has typically a noticeable elliptical section, with the minor axis connecting the most widely-separated points on the dorsal and ventral sides, while the principal thickening is at the other two sides, filling in the apices of the ellipse so as to give a circular section interiorly. These two forms, however, pass so gradually one into the other that it really seems inadvisable to separate them—certainly at present. Also, in limestone-beds, the representatives of the species under consideration have relatively a much thicker test and a perfectly-circular section; but occasionally this character is possessed by examples now obtained from clay-deposits, as at Honeybourne clay-pit.

Although these three slightly-different forms are perhaps best considered under one specific name at present, it is certainly

advisable that the particular form referred to by an author should be clearly indicated. Thus *Dentalium parvulum* proper may be understood to embrace those thin-walled shells which have a circular to slightly-elliptical transverse section—the commonest form; *D. parvulum* α those with an elliptical section; and *D. parvulum* β the thick-walled forms, with a very perfect circular section.

The specimens mentioned in the subjoined list have all passed through my hands, and the majority are in my collection:—

Dentalium parvulum.—*margaritati?* Chipping Norton, Oxfordshire (form β: identified by Slatter with *D. minimum*, Strickland-Buckman); *Valdani*, Leckhampton Road clay-pits, Cheltenham (Holl Colln., Nat. Hist. Mus., etc.); Battledown Brickworks, Cheltenham; Clay-pit (disused), Hucclecote, near Gloucester; *Jamesoni* (about), Bishop's Cleeve Station, near Cheltenham; *armati* (& *Jamesoni?*), railway-cutting, Aston Magna, near Moreton-in-the-Marsh; *armati-Jamesoni*, railway-cutting, Toddington, near Cheltenham; *armati*, Folly-Lane clay-pit, Cheltenham; *oxynoti-armati*, Gasworks, Gloucester (& form α); *Turneri*, Honeybourne clay-pit, near Evesham (form β: Slatter Colln., Nat. Hist. Mus.); *rotiformis*, Bengeworth clay-pit, Evesham (form α: Nat. Hist. Mus.)[1]; *rotiformis?* Aldington Leys, near Evesham (form α: Slatter Colln., Nat. Hist. Mus.)[1]; *marmoreæ*, clay from pond a quarter of a mile north of Bamfurlong, near Cheltenham (form α); *Birchi?* Besford clay-pit, near Defford, Worcestershire (Slatter Colln., Nat. Hist. Mus.).[1]

DENTALIUM SUBOVATUM, sp. nov. (Pl. XLV, fig. 7.)

T.f. 1876. Tate, 'The Yorkshire Lias' pl. x, fig. 18.
T.l. Redcar [Yorkshire].
H. 'Lower Lias' (*A. angulatus*-zone).
η. [*marmoreæ*.]
Colln. Tate, Museum of Practical Geology, Jermyn Street.

Syn. 1855. *Dentalium compressum*, Terquem, 'Paléontologie de Hettange' Mém. Soc. Géol. France, ser. 2, vol. v, p. 280.
1865. *D. compressum*, Terquem & Piette, *pars?* 'Le Lias Inférieur de l'Est de la France' Mém. Soc. Géol. France, ser. 2, vol. viii, p. 67.
1876. *D. limatulum*, Tate, 'The Yorkshire Lias' pp. 332–33 & pl. x, fig. 18.

Diagnosis.—Shell small, slightly curved; transverse section subovate exteriorly, oval interiorly, but becoming more nearly circular in specimens which have a flat or very slightly-convex dorsal side; surface-ornamentation consisting of fine transverse lineæ.

Remarks.—The specimens from the Lower Lias of Redcar identified by Tate with his *Dentalium limatulum* from the 'Zone of *Belemnites acutus*,' Cloverly (Shropshire), do not appear to belong to the same species. I have examined what remains of the holotype of *Dentalium limatulum*, Tate (which is deposited in the Geological Society's Museum), and those specimens from Yorkshire, and find that the transverse section of the former is subpentagonal, while that of the one chosen from the latter series by Tate for figuring in 'The Yorkshire Lias' is subovate. This feature, however, is better shown in certain topotypes which are preserved in the Museum of Practical Geology, Jermyn Street.

In those specimens which have a flat or very slightly-convex dorsal side the aperture is nearly circular, and in this condition it resembles certain forms which belong without doubt to a certain stage in the development of *Dentalium subtrigonale* (p. 589). Indeed,

[1] These were identified by Slatter as *Dentalium minimum*.

it is with this stage of *D. subtrigonale* that the present species has the greatest affinity. *D. subovatum*, however, is from a deposit of *marmoreæ-Birchi (?)* date, and is a very much smaller species than *D. subtrigonale*—an *armatum*-zone fossil. The former has a subovate transverse section, and, from the few specimens which it has been possible to examine, this seems a fairly-constant character: the exception being, as already stated, when the dorsal side is flattened. In *D. subtrigonale* the section is triangular, with a blunt and noticeable ventral carina in the neanic stage.

The specimen figured as *Dentalium limatulum* by Tate in 'The Yorkshire Lias' is between 9 and 10 millimetres in length: the diameter of the anterior end measuring slightly over 1 mm., and that of the posterior end 0·75 mm. The transverse lineæ, on the whole, are much finer than in *D. subtrigonale*.

Terquem's remarks on the species that he dealt with from the 'grès infra-liasique de Hettange,' which he hesitatingly referred to d'Orbigny's *Dentalium compressum*, were as follows [translation]:—

'This shell, found in a crypt of *Saxicava*, is very slender and fragile, strongly compressed, shiny, subarcuate, and ornamented with very fine, closely-set striæ, visible only with a strong lens.—Very rare.'

'Observation.—It is difficult to point out a specific character for shells the shape of which presents so little variation; for this reason we have adopted the denomination of M. d'Orbigny, although it has been applied to a species from the Middle Lias.'

From this there can be little doubt that *Dentalium compressum*, Terquem, is referable to the present species. Brauns, however, regarded Terquem's shell as being the same as *D. etalense*, Terq. & Piette. In his notes he comments upon the fact that *D. etalense*, Terq. & Piette, is not compressed, and observes that this characteristic feature is also wanting in *D. compressum*, Terquem. But it is not: Terquem distinctly says that this fossil is 'strongly compressed.'

With regard to the specimens identified with *Dentalium compressum*, d'Orbigny, by Terquem & Piette, those from the 'calcaire à *A. bisulcatus* [hemera rotiformis ?] de Jamoigne,' and the 'grès à *A. angulatus* de Saint Menge,' probably belong to *D. subovatum*; while those from the 'grès à *B. acutus* d'Étales et de Maubert,' may belong to *D. trigonale*, Moore. Brauns would refer these also to *D. etalense*.

DENTALIUM SUBQUADRATUM, sp. nov. (Pl. XLV. fig. 8.)

T.f. Transverse section, Pl. XLV, fig. 8.
T.l. Honeybourne (clay-pit ?), near Evesham.
H. 'Lower Lias.' Sinemurian.
η. *Turneri* (about).
Colln. Slatter, Nat. Hist. Mus. (G. 10807).

Diagnosis.—Shell small, slightly curved, test thin; transverse section subquadrate exteriorly and interiorly; surface smooth. The posterior portion is more angular than the anterior, in which the dorsal margin is slightly broadened. Length = 11 millimetres; diameter of anterior end = about ·5 mm.

Remarks.—Only one example of this species, which is well-defined, has passed through my hands.

DENTALIUM SUBTRIGONALE, sp. nov. (Pl. XLV, figs. 2 *a*–2 *d*.)

T.f. Pl. XLV, figs. 2 *a*–2 *d*.
T.l. Folly-Lane clay-pit, Cheltenham.
H. Pliensbachian.
η. *armati.*
Colln. L. Richardson.

Syn. 1904. *Dentalium* aff. *limatulum*, Richardson, 'Handbook to the Geology of Cheltenham' p. 219, but not pl. xv, fig. 2.

Diagnosis.—Shell small, thick (for its size); transverse section subtriangular exteriorly, circular to subobvate interiorly; dorsal sides convex, but becoming flattened to convex towards the anterior end in senile specimens. Sides subconvex anteriorly (especially in senile forms, as in Pl. XLV, fig. 2 *c*); but flat posteriorly, where they usually converge regularly until within a short distance of the ventral side, when they are directed vertically to meet that side at right angles, thereby giving rise to a prominent carina; the surface-ornamentation consists of fine, oblique, transverse lineæ.

Remarks.—*Dentalium subtrigonale* presents three different outlines in transverse section. The majority of the specimens found at the Folly-Lane clay-pit, when cut transversely anywhere in the posterior half, present the outline shown in Pl. XLV, fig. 2 *b*; a few when cut anywhere in the anterior half, a more or less triangular section; while others (chiefly mature forms) have only a faint blunt ventral margin at or near the anterior extremity, and slightly-convex lateral and dorsal surfaces (fig. 2 *c*). Some very mature forms give an ovate transverse section of the anterior end, and have a relatively-thick test with more conspicuous lineæ.

DENTALIUM TERQUEMI (Tate MS.), sp. nov.

T.f. None.
T.l. Aiglemont.
H. 'Assise à *A. angulatus*.' [Hettangian.]
η. [*marmoreæ.*]
Colln. ——.

Syn. 1865. *Dentalium giganteum*, Terquem & Piette, *pars* (non Phillips), 'Le Lias Inférieur de l'Est de la France' Mém. Soc. Géol. France, ser. 2 vol. viii, pp. 67–68.

Diagnosis.—Shell ornamented with numerous, very fine, closely-set lineæ. Diameter of transverse section = at least 2 millimetres.

Remarks.—Concerning the forms which Terquem & Piette referred to Phillips's species, these authors remarked (translation):—

'We refer to this species some fragments from 8 to 10 millimetres in length by 2 in breadth, and ornamented with numerous very fine and closely-set striæ; the specimens which we possess from the Middle Lias of the Moselle, *Plicatula-spinosa* zone, are more perfect, have a diameter of 5 millimetres for a length of 50, and present the same ornamentation.

'Locality: Zone of *A. angulatus* of Aiglemont.'

In Ralph Tate's manuscript note-book, which was very kindly

given to me by the late Prof. J. F. Blake, the fossils which Terquem & Piette identified with Phillips's *Dentalium giganteum* are described as '*Dentalium Terquemi*, n. sp.' Tate thought therefore that Terquem & Piette's fossils were wrongly identified, and created for their reception the specific name of *D. Terquemi*.

As I have not seen the specimens, and since the authors say that the ornamentation of the shells from the *Plicatula-spinosa* and *angulata*-zones is similar, of course I do not seek to argue that the specimens from these horizons belong to distinct species; but this certainly seems probable, and it is also possible that while those from the *Plicatula-spinosa* zone have been correctly identified with *Dentalium giganteum*, Phillips, those from the *angulata*-zone require to be distinguished therefrom, and may bear Tate's suggested name of *D. Terquemi*. This seems to be the most legitimate conclusion, until more information is available.

DENTALIUM TRIGONALE, Moore. (Pl. XLV, figs. 4 *a–c* & 5 *a*–5 *d*.)

T.d. 1867. Proc. Somerset Arch. & Nat. Hist. Soc. vol. xiii, p. 202.
T.f. *Ibid.* pl. v, fig. 22.
T.l. Camerton [near Radstock, Somerset].
H. 'Middle Lias.' [Pliensbachian.]
η. [*armati.*]
Colln. Moore, Bath Museum.

Syn.[1] ? 1858. *Serpula triedra*, Quenstedt, 'Der Jura' pp. 200, 329 & pl. xxiv, fig. 55.
1875. *Dentalium compressum*, Tate, Quart. Journ. Geol. Soc. vol. xxxi, p. 504.
1904. *Dentalium* aff. *limatulum*, Richardson, 'Handbook to the Geology of Cheltenham' p. 219 & pl. xv, fig. 2.
Non ? 1850. *Dentalium compressum*, d'Orbigny, 'Prodrome de Paléont.: Liasien' vol. i, no. 135, p. 233.

Protolog (*T.d.*).—'Shell triangular, thick, sheath-like, elongate, smooth, slightly curved, sides flattened, or rather convex, covered by numerous very fine annular oblique concentric striæ, every fourth or fifth of which is slightly raised and increased in thickness; section of the shell somewhat triangular, the base being thick, broadest, and with a slight sinus, whilst the opposite or dorsal [*sic*] margin is obtusely angular or carinated; aperture elliptical.'

Moore's description mentions, as being possessed by a certain form, characters which really belong to two distinct species. The sides 'are flattened, or rather convex,' he wrote, and 'the dorsal [*sic*][2] margin is obtusely angular or carinated.' If the sides are flattened and the ventral margin carinated, then the form belongs to the species *D. subtrigonale*: if rather convex, with an obtuse ventral margin, to the species *D. trigonale*.

Moore possessed three fragments of *Dentalium (?) trigonale*, which he obtained from the Middle Lias of Camerton. From these syntypes he restored what he believed to be the shell of *Dentalium (?) trigonale*, but he portrayed a specimen very much more erect than the evidence at his disposal warranted. It is probable, however,

[1] See also *Dentalium subovatum*, p. 587.
[2] Should be 'ventral.' The concave side of the shell is the dorsal.

that Moore himself detected and would have rectified this error had he and Tate been spared to do so. Attached to the tablet which bears the specimens in the Bath Museum are certain lithographs representing the true nature of the fragments. I now understand that these lithographs were taken from one of a number of plates drawn to illustrate a monograph of the 'British Liassic Gasteropods,' by Moore & Tate, for the Palæontographical Society. But neither these authors nor Edward Wilson, who had also set himself the same task, lived to see its accomplishment. The figures of *Dentalium trigonale*, which were to have appeared in Moore & Tate's monograph, are reproduced (by kind permission of the late Prof. Blake, in whose possession were the plates referred to) in Pl. XLV, figs. 5 *a*–5 *d*. They leave no doubt as to the specific position of the Gloucestor Gasworks forms.

While it is easy to separate the trianguloid types of *Dentalia* when the actual specimens are available for examination, there is a considerable difficulty in dealing with synonymy, and the question as to whether *Dentalium compressum*, d'Orb., is really a *Dentalium*, and the fragmentary condition of the holotype of *Dentalium limatulum*, Tate, do not simplify matters. The results arrived at by students of the Dentaliidæ in this country have been to refer any Liassic *Dentalium* with a section suggestive of a triangle to either *D. limatulum*, Tate, or *D. compressum*, d'Orbigny. By Tate, Moore's species *D. trigonale* was associated with *D. compressum*, d'Orb.; and the authors of the list of fossils in the Geological-Survey Memoir on the Lias (p. 352) went further than this: they apparently regarded the species *D. trigonale*, *D. compressum*, and *D. gracile*, Moore, as all synonymous with *D. elongatum*, Münster. Very much the same results were obtained on the Continent: all specimens with a transverse section approaching the triangular were relegated to d'Orbigny's species—hesitatingly, it is true, by some authors.

The history of the 'trianguloid' types of *Dentalium* will be found detailed in this section and in those on *Dentalium limatulum*, *D. subovatum*, and *D. subtrigonale*.

The ventral side is the thickest in *Dentalium trigonale*, but not the broadest of the three as stated by Moore. It is flattened at the anterior end for a space of about 2 millimetres therefrom, while the remainder is concave. The sides are slightly convex, converging to form a subacute or obtuse carina along the ventral margin, which is thus not blunt (as is the case with the species *D. subtrigonale*). Occasionally the extreme posterior portion becomes somewhat carinated (but it is an obtuse carina) and the concavity of the ventral portion gives rise to more or less prominent keels where that side joins the other two. The relatively-thicker test of the shell-fragments from Radstock, when compared with those from Gloucester, is easily accounted for by the lesser quantity of lime in the water inhabited by the latter: at Gloucester the *oxynotum-armatum*-beds are clay-deposits; while at Radstock the deposit of

armati-hemera consists of cream-coloured, slightly ironshot limestones.

Moore referred this 'curious little shell' with some doubt to the genus *Dentalium*, but his diagnosis was perfectly correct.

Quenstedt obtained specimens of the tube of a *Dentalium*, or of some tubicolous annelid, which very much resembled it, from the *margaritatus*-beds of Dörlbach, and figured and described it as *Serpula triedra* ('Der Jura' pl. xxiv. fig. 55), but admitted that the three sides were flat and smooth like those of a *Dentalium*. At a later page (329) of the same work he showed his uncertainty as to the accuracy of the generic diagnosis, for he wrote:

'In the Lias I find very few [*Dentalia*], perhaps the *Serpula triedra* pag. 200 would be better named *Dentalium* on account of its smoothness.'

Provisionally this fossil may be regarded as *Dentalium trigonale*, Moore. This was also Tate's view, as shown by the note-book of his in my possession; but it should be noticed that Quenstedt's fossil is a *margaritatus*-bed form, more equilateral, and probably another species.

As might be expected from the very brief description of *Dentalium compressum* given by d'Orbigny—that it is a 'species strongly compressed, subcarinated, smooth' [1]—much difficulty has arisen in identifying the form.

Dentalium compressum, Terquem, is probably the same as my *D. subovatum* (see p. 587): for, as Terquem rightly remarks, d'Orbigny's *Dentalium* is a Middle Liassic shell, while his came from the 'grès infra-liasique de Hettange,' and has the same range in time as *D. subovatum*. Terquem, in defence of his acceptance of d'Orbigny's specific name for his fossil, felt it necessary to state that it was difficult to point out a specific character in a shell belonging to a group subject to so little variation.

In 1869 E. Dumortier [2] complained of d'Orbigny's too brief description and wondered whether *D. compressum* could be the same as Moore's *D. trigonale*, but he made no other remark. In 1875, however, Tate concluded that this was actually the case, and recorded, in his list of fossils from the Radstock Lias,

'*Dentalium compressum*, D'Orb. (*D. trigonalis*, Moore). Two examples, Camerton; four examples, Radstock, Munger, and Clan Down.' (Quart. Journ. Geol. Soc. vol. xxxi, p. 504.)

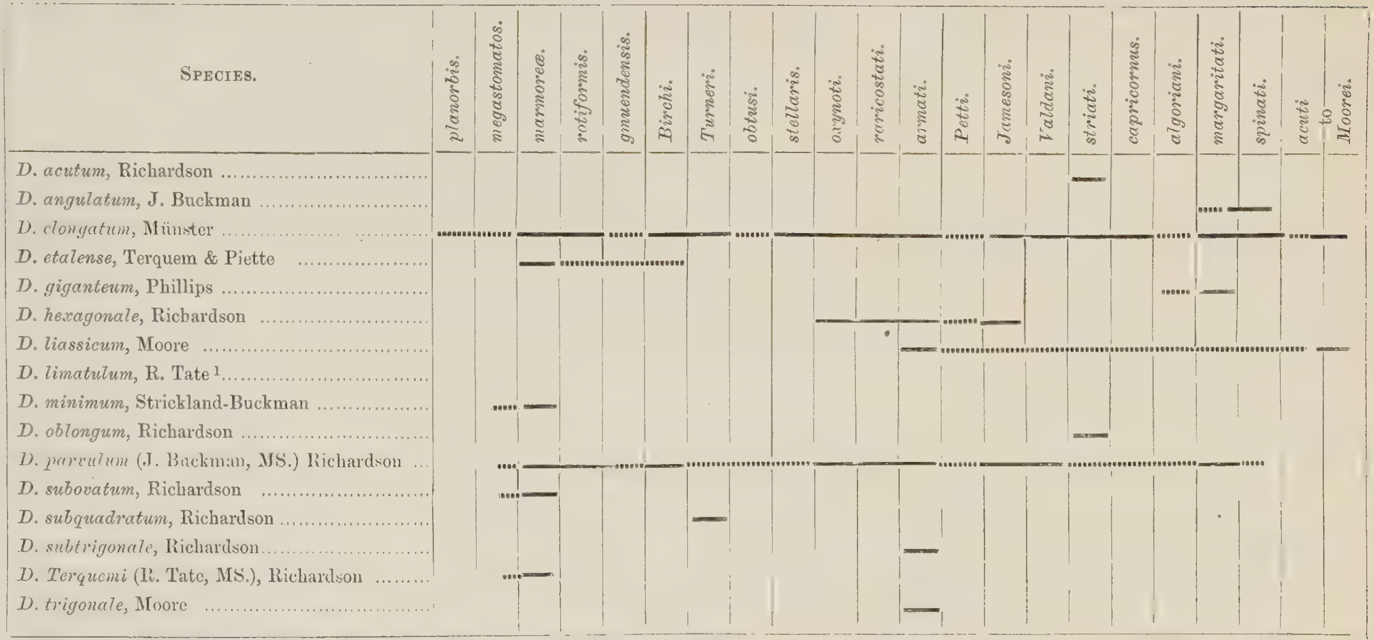
In order to endeavour to solve this problem I communicated with M. A. Chenevrier, Assistant Palæontologist at the National Museum of Natural History, Paris, who replied [translation]:

'D'Orbigny's collection contains only a single specimen of this species, coming from Chalon-sur-Saône. It is a fragment of a calcareous tube, slightly

[1] 'Prodrome de Paléontologie stratigraphique: Liasien' 1850, no. 135.

[2] 'Dépôts Jurassiques du Basin du Rhône' pt. iii: 'Lias Moyen' June 1869 p. 160.

TABLE SHOWING THE VERTICAL RANGE OF THE SPECIES OF LIASSIC *DENTALIA* DEALT WITH IN THIS PAPER.



[1] From the 'Zone of *Belemnites acutus*.'

NOTE.—A broken line means that a species probably (and in some cases, must have) lived during the time indicated, but that no remains of the shell have been found in the deposits of that date.

Dentalium elongatum, Münster, and *D. liassicum*, Moore, are the only two species of *Dentalia* that have been recorded from the Upper Lias (Toarcian) of the British Isles.

incurved, smooth exteriorly, of which the total length is 23 mm.; this fragment has been in part broken, and the length of the well-preserved portion does not exceed 13 mm. The section is elliptical (the greatest dimension of this section, in the middle, being 3 mm., and the least dimension 2 mm.). Upon the whole it is a poor specimen, scarcely characteristic, of which the interest is in presenting so aberrant a form for a *Dentalium*.'

He adds in a postscript that the compressed form of the tube is certainly not due to any mechanical action after fossilization: 'the tube is intact in the part considered.'

From M. Chenevrier's useful description, one would feel disposed to think that *D. compressum*, d'Orb., is not a *Dentalium* at all, but the shell of a tubicolous annelid.

The plate illustrating this paper has been prepared by Mr. J. W. Tutcher, of Bristol, and Mr. G. W. S. Brewer, F.G.S., of Cheltenham, for whose invaluable assistance I am deeply grateful; while to Major E. F. Becher, of Cheltenham, I am indebted for the photograph reproduced in the text on p. 580.

EXPLANATION OF PLATE XLV.

Figs. 1 *a*, 1 *b*, & 1 *c*. *Dentalium hexagonale*, sp. nov. (p. 581).
a=Specimen, × 2; *b*=Transverse section, × 4; *c*=Portion of test enlarged.
Hemerae: *oxynoti-armati*. Locality: Gasworks, Gloucester. Colln.: L. Richardson.

2 *a*, 2 *b*, 2 *c*, & 2 *d*. *Dentalium subtrigonale*, sp. nov. (p. 589).
a=Specimen, × 2; *b*=Transverse section, posterior end, × 4; *c*=The same, anterior end, × 4; *d*=Portion of test enlarged.
Hemera: *armati*. Locality: Folly-Lane clay-pit, Cheltenham. Colln.: L. Richardson.

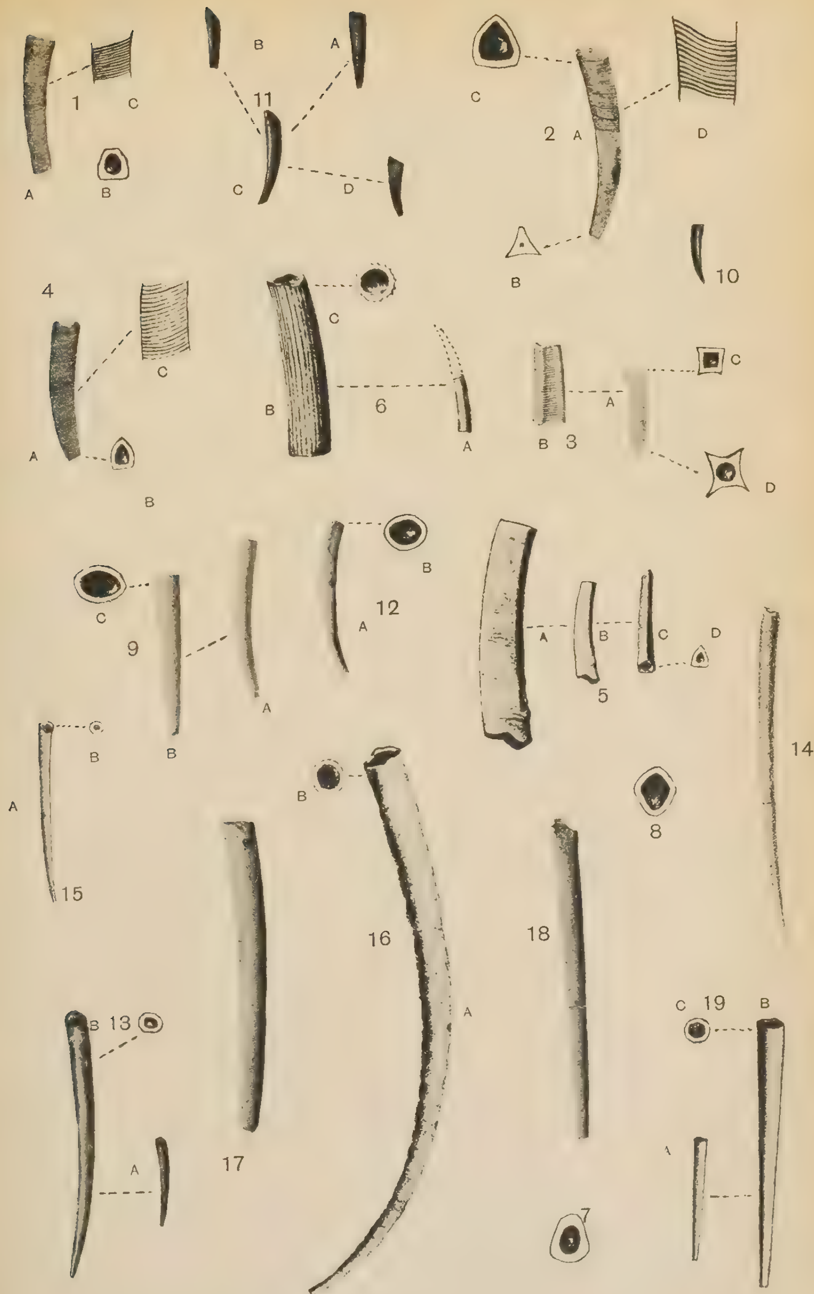
3 *a*, 3 *b*, 3 *c*, & 3 *d*. *Dentalium oblongum*, sp. nov. (p. 585).
a=Specimen, × 2; *b*=Portion of test enlarged; *c*=Transverse section of anterior end, × 4 (about); *d*=The same, posterior end, × 7 (about).
Hemera: *striati*. Locality: Railway-cutting, near Cheltenham. Colln.: L. Richardson.

4 *a*, 4 *b*, & 4 *c*. *Dentalium trigonale*, Moore (p. 590).
a=Specimen, × 2; *b*=Transverse section of the posterior end, × 2 (a little more); *c*=Portion of test enlarged.
Hemerae: *oxynoti-armati*. Locality: Gasworks, Gloucester. Colln.: L. Richardson.

5 *a*, 5 *b*, 5 *c*, & 5 *d*. *Dentalium trigonale*, Moore.
a=View of holotype, × 2 (a little more); *b*=The same, natural size; *c*=View of ventral side of holotype, natural size; *d*=Transverse section, natural size.
Hemera: [*armati*]. 'Middle Lias.' Locality: Camerton, near Radstock (Somerset). Colln.: Charles Moore, Bath Museum.

6 *a*, 6 *b*, & 6 *c*. *Dentalium liassicum*, Moore (p. 581).
a=View of holotype (slightly enlarged); *b*=The same, × 4 (about); *c*=Transverse section, × 4 (about).
Hemera: [*armati*]. Locality: Camerton, near Radstock (Somerset). Colln.: Charles Moore, Bath Museum.

Fig. 7. *Dentalium subovatum*, sp. nov. (p. 587). Transverse section, × 6.
Hemera: [*marmoreæ*]. 'Zone of *Ammonites angulatus*.' Locality Redcar (Yorkshire). Colln.: R. Tate, Museum of Practical Geology, Jermyn Street.



J. W. Tutcher, Photo.
G. W. S. Brewer, del.

Bemrose, Collo.

LIASSIC DENTALIIDÆ.

Fig. 8. *Dentalium subquadratum*, sp. nov. (p. 588). Transverse section (posterior end), × 4.
Hemera: [*Turneri* about]. Locality: Honeybourne [clay-pit?, near Evesham]. Colln.: Slatter, British Museum, Nat. Hist. [G. 10807].

Figs. 9 *a*, 9 *b*, & 9 *c*. *Dentalium parvulum* (J. Buckman, MS.), sp. nov. (p. 585), var. *a*.
a=Lateral view, × 2; *b*=Dorsal view, × 2; *c*=Transverse section, × 4.
Hemera: *rotiformis* (*teste* S. S. Buckman). Locality: Clay-pit, Bengeworth, Evesham. Colln.: L. Richardson.

Fig. 10. *Dentalium acutum*, sp. nov. × 2 (p. 574).
Hemera: *striati*. Locality: Railway-cutting, 'Dixton West,' near Gotherington, near Cheltenham. Colln.: L. Richardson.

Figs. 11 *a* & *b*. *Dentalium acutum*, sp. nov., natural size.
11 *c* & *d*. Probably the same, × 2.
Hemera: [*striati?*]. 'Lower Lias.' Locality: 'Worcestershire.' Colln.: H. E. Strickland, Sedgwick Museum, Cambridge.

12 *a* & 12 *b*. *Dentalium parvulum*, sp. nov. (p. 585).
a=Specimen, × 2; *b*=Transverse section, × 4.
Hemera: *Valdani*. Locality: Leckhampton-Road Clay-pits, Cheltenham. Colln.: Geological Society of London (type): L. Richardson (figured specimen).

13 *a*, 13 *b*, & 13 *c*. *Dentalium minimum*, Strickland-Buckman (p. 582).
a=Specimen, × about 3; *b*=The same, × about 9; *c*=Transverse section, × about 9.
Hemera: [*marmoreæ*]. Locality: Island Magee. Colln.: Tate, Museum of Practical Geology, Jermyn Street.

Fig. 14. *Dentalium etalense*, Terquem & Piette (p. 578). From a photograph of the type-figure.
Hemera: [*marmoreæ*]. Locality: Saint-Menge.

Figs. 15 *a* & 15 *b*. *Dentalium etalense*, Terquem & Piette.
a=Specimen, natural size; *b*=Transverse section, natural size.
Hemera: [*marmoreæ*]. Locality: Stout's Hill. Colln.: Moore, Bath Museum.

16 *a* & 16 *b*. *Dentalium giganteum*, Phillips (p. 579).
a=Specimen, natural size; *b*=Transverse section, natural size.
Hemera: [*margaritati*]. Locality: Hawsker Cliff. Colln.: Tate, Museum of Practical Geology, Jermyn Street [8000].

Fig. 17. *Dentalium elongatum*, Münster (p. 575). × 2.
Hemera: *armati*. Locality: Folly-Lane clay-pit, Cheltenham. Colln.: L. Richardson.

18. *Dentalium elongatum*, Münster, var. *gracile*, Moore. × 2.
Hemera: *armati*. Locality: Hunting-Butts tunnel (G.W.R.), Cheltenham. Colln.: L. Richardson.

Figs. 19 *a*, 19 *b*, & 19 *c*. *Dentalium 'gracile,'* Moore (var. of *D. elongatum*, Münster). (P. 576.)
a=Holotype, natural size; *b*=The same, × $2\frac{1}{3}$; *c*=Transverse section, × $2\frac{1}{3}$.
Hemera: [*armati*]. Locality: Camerton. Colln.: Moore, Bath Museum.

Discussion.

Mr. R. S. Herries expressed a hope that there would be some information in the paper as to the method of occurrence of the various forms of *Dentalium*. He called attention particularly to the occurrence of *D. giganteum* in the Lias of Yorkshire. Enormous numbers of this fossil occur in layers of sandstone about the junction of the *margaritatus* and *capricornus*-zones. These layers

are confined within a few feet vertical, but extend from Huntcliff to Robin Hood's Bay, some 25 miles, wherever there is an exposure. The form then disappears as suddenly as it came into existence.

Mr. E. T. Newton remarked on the difficulty of discussing a paper of this character, and enquired to what extent the Author had referred the Dentaliidæ to particular zones.

Prof. Watts, in reply, read a portion of the paper including a description of one of the new species of *Dentalium*.

28. *The* Ordovician Rocks *of* Western Caermarthenshire.

By David Cledlyn Evans, F.G.S. (Read May 9th, 1906.)

[Plate XLVI—Map.]

Contents.

I. Introduction.

This little contribution to the geology of Caermarthenshire is the result of leisure-work done during some years' residence in the district.

The ground dealt with is practically identical with that examined by the late Thomas Roberts, M.A., whose notes were published in the Quarterly Journal of this Society for May 1893 (vol. xlix): that is, from the River Cywyn on the east to the Tave on the west, and from the base of the Old Red Sandstone on the south to the top of the *Dicranograptus*-Shales on the north—roughly, a rectangular tract of country 11 miles long by 6 miles wide.

(1) Previous work done.—George Owen, of Henllys, as long ago as the year 1595, had given some attention to the economic geology of the district, and in a manuscript, an extract from which is appended to Richard Fenton's 'Historical Tour through Pembrokeshire,' refers to certain limestone-bands that occur here, noting, by the way, the proximity of limestones to the coal-deposits of the country. This inference has, from time to time, led to much expenditure of labour and money in a futile search for coal. Levels were driven and pits were sunk: but, of course, no coal was found—except in the fertile imagination of credulous though well-meaning people.

The district was examined by the officers of the Geological Survey in 1842, and the results of their labours are recorded in Sheets xli (Map) and 13 (Sections).

John Phillips, in his Memoir on the Malvern and Abberley Hills, records a fairly-long list of fossils collected here. The graptolitiferous rocks of the district have had the attention of Prof. Lapworth; and the late Thomas Roberts, M.A., of Cambridge, had proceeded some way with the working-out of the ground when his valuable life was cut short, leaving the task unfinished. His notes, however, fell into competent hands, and were placed on record, as stated above. They have proved of great help to me, and may be considered as the basis of this humble effort.

Between the years 1885 and 1899, I got together a fairly-large and representative collection of fossils. The graptolites were exhibited at the meeting of the Royal National Eisteddfod held at Merthyr Tydvil in the summer of the latter year; and again, a general collection was exhibited at the meeting held at Llanelly in 1902.

A portion of the area is now being surveyed by the officers of H.M. Geological Survey—Messrs. T. C. Cantrill, B.Sc., and H. H. Thomas, M.A., B.Sc.; with them I have had the pleasure of going over much of the ground, and to them I am indebted for much kind encouragement and valuable advice.

(2) References.—

Richard Fenton. 'Historical Tour through Pembrokeshire' (Appendix No. 17) 1811. 4to. London.
The Geological Survey (1842) Sheets xli & 13.
R. I. Murchison. 'The Silurian System' 1839.
H. Maclauchlan. Trans. Geol. Soc. ser. 2, vol. vi (1842) p. 557.
John Phillips. 'The Malvern Hills compared with the Palæozoic Districts of Abberley, &c.' Mem. Geol. Surv. vol. ii, pt. i (1848).
J. W. Salter. 'Monograph of the British Trilobites' Palæont. Soc. 1864–1885.
Thomas Davidson. 'Monograph of the British Fossil Brachiopoda' Palæont. Soc. 1851–1886.
Charles Lapworth. 'On the Geological Distribution of the Rhabdophora' Annals & Mag. of Natural History, ser. 5, vol. iv (1879) pp. 333, 423; & vol. v (1880) pp. 45, 273, & 358.
J. E. Marr & T. Roberts. 'The Lower Palæozoic Rocks of the Neighbourhood of Haverfordwest' Quart. Journ. Geol. Soc. vol. xli (1885) p. 476.
Thomas Roberts. 'Notes on the Geology of the District West of Caermarthen' Quart. Journ. Geol. Soc. vol. xlix (1893) p. 166.
Miss M. C. Crosfield & Miss E. G. Skeat. 'On the Geology of the Neighbourhood of Caermarthen' Quart. Journ. Geol. Soc. vol. lii (1896) p. 523.
Miss G. L. Elles & Miss E. M. R. Wood. 'Monograph of the British Graptolites' Pt. i. Palæont. Soc. 1901–1902.

II. General Remarks.

(1) Physical Structure.—The dips and the general relation and arrangement of the various rocks prove that the area is, in the main, a denuded anticlinal fold of considerable extent, with an east-and-west axis. The ground has, however, been much complicated by inner and minor folds accompanied by a great deal of faulting and crushing. There is abundant evidence that the main fold was thrown over to the south, and that further complications have been brought about by subsequent fractures and thrusts among the minor, subsidiary folds, with the result that, in some instances, older beds have been brought to the surface and pushed some distance over newer ones. Examples of overfolding and thrusting are numerous and perplexing, especially when they occur in shales of *Tetragraptus*- and *Didymograptus-bifidus* age.

As a natural outcome of these great closing-up movements, rocks that had been deposited over wide areas and under very different conditions have been brought together within the comparatively-narrow limits of the district under consideration. In other words, points that are now within 3 or 4 miles of one another were, previous to the movements, four or five times that distance apart. Certain beds in the northern limb of the fold are lithologically distinct from corresponding beds, that is, beds of the same age, in the southern limb; and, what is of greater significance, there is considerable difference in the character of the faunas. For instance, on the south the *Didymograptus-Murchisoni* Beds, if at all present, are very poorly developed; the *Asaphus-tyrannus* Beds are highly calcareous, and in one instance thickly-bedded limestones; and the Bala-Caradoc rocks are well developed, and contain two or three strong bands of limestone. While on the north the *D.-Murchisoni* Beds are well-formed and persistent; the *Asaphus-tyrannus* Beds are thin and ashy, with hardly a trace of calcareous matter; and the Bala-Caradoc rocks are represented by some blue-black mudstones which make but a poor show. On the north, there is also a calcareous development in the *Dicranograptus*-Shales with a rich graptolite-fauna—features which are entirely absent on the south. (See figs. 1 & 2, p. 600.)

(2) Faulting.—The majority of the faults, as might be expected, are strike-faults, running east and west. Those on the north usually hade northward at various angles, many of them being thrusts. On the south there are but few thrusts, the majority of the faults being normal. There are very few dip-faults, and where they occur they are of small extent.

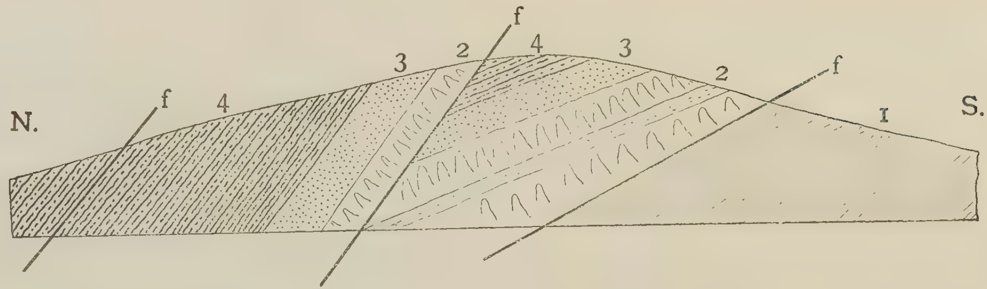
The rocks forming the core of the anticline are much crushed. Especially is that the case along a line traced from near Banc-y-felin to Llangynin Church, and thence to Aberddeunant. Near that place, the line of disturbance probably splits, forming faults which account for the features of the country farther west; that is, the bringing to the surface of older and more gritty beds north of Whitland—these latter having also suffered much from folding and faulting.

There is another line of disturbance running from near Asgood, past Blue Boar and Llaindelyn to a point south of Clôg-y-frân. This disturbance presumably accounts for the disappearance eastward of the Woolston and Clôg-y-frân ashes.

The ground round Clôg-y-frân and Forest has been much affected by faulting. At the former place, strata of *Didymograptus-bifidus* and *Asaphus-tyrannus* age, and two types of Bala-Caradoc rocks, can be studied in the farmyard; and at the latter Bala-Caradoc rocks have been sandwiched between two slices of *D.-bifidus* Beds in one locality, and between *D.-bifidus* beds and Lower Llandovery (?) beds in another close by, while the *D.-bifidus* Beds themselves, including the ashes, have been very much cut up.

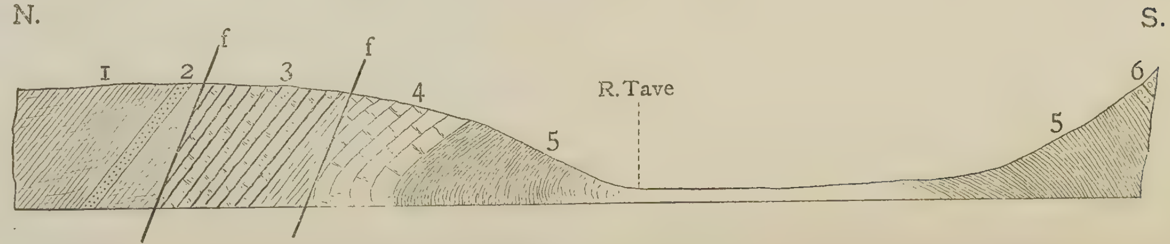
The Bala-Caradoc rocks west of Llanddowror have also suffered a

Fig. 1.—*Semi-diagrammatic section from north to south, near Caerlleon.*
(Marked on the map, Pl. XLVI, as 'Section V.')



1 = *Didymograptus-bifidus* Beds.
2 = *Didymograptus-Murchisoni* Beds.
3 = *Asaphus-tyrannus* Ash.
4 = *Dicranograptus*-Beds.
f f = Faults.

Fig. 2.—*Semi-diagrammatic section from north to south, near Clôg-y-frân.*
(Marked on the map, Pl. XLVI, as 'Section IV.')



1 = *Didymograptus-bifidus* Beds.
2 = *Didymograptus-bifidus* Ash.
3 = *Asaphus-tyrannus* Limestones.
4 = Bala Limestones.
5 = Redhill and Slade Beds.
6 = Conglomerates, etc.
f f = Faults.

great deal, so much so in fact, that only an imperfect idea of the actual conditions can be gleaned from what can be represented on a 1-inch map.

North of the main axis, a line of extensive disturbance commences near Castell-gorfod, and runs slightly north of west, past Penlan and Nant-yr-eglwys to Llanboidy, and thence to Llanglydwen, the structure of the ground increasing in complexity as it passes westward. Some of the ground near Penlan, Nant-yr-eglwys, and south of Eglwys-fair-a-churig is very obscure and difficult of interpretation.

(3) Cleavage.—The rocks in the northern limb of the fold are more or less affected by cleavage. In the lower beds it is slight, but very pronounced in the upper, increasing in intensity as it is traced northwards. Thus the *Didymograptus-bifidus* Beds are only slightly affected, the *D.-Murchisoni* Beds more so, and the *Dicranograptus*- and higher beds so much at some points as to become quite slaty.

The faulting was anterior to the cleavage, for the latter is quite independent of the former. Dips vary a great deal both in inclination and in direction, but the cleavage-planes are tolerably uniform and constant, running east and west with an inclination of about 45° north, or, occasionally, a little east of north.

On the south there is an almost complete absence of cleavage; only in one or two localities—in black *Dicranograptus*-Shales—can its occurrence be suspected.

(4) Igneous Rocks.—North of Llanboidy and extending from a point about a quarter of a mile west of Maesgwynne House to the Fenni Valley, near Maencoch, there is an intrusion of diabase. This 'dyke' crosses outcrops of *Didymograptus-bifidus* Beds, *Asaphus-tyrannus* Beds, and, for some distance, penetrates into *Dicranograptus*-Shales. It also crosses at least one of the main faults, without appearing to be in the least displaced by it. In some places, the rocks in contact with the dyke show evidence of slight baking, but the portion affected is only a few inches thick.

At Glyntâf House, a mile south of Llanglydwen, are two exposures of diabase extending for a short distance east of the Tave, the bed of which is here much encumbered by huge masses of the rock. The northernmost is seen in section in a railway-cutting near the round cottage, as well as in the old quarry behind the cottage itself. There it is seen to cut obliquely through cleaved ash of a greyish-green colour. The other exposure also abuts on the railway, but about a quarter of a mile farther south. This dyke has been somewhat extensively quarried immediately west of Glyntâf, but seems to die out at no great distance to the east. West of the Tave both dykes are much more developed, and seem to be an eastward extension of the volcanic rocks of the Prescelly country farther west.

(5) Contour, etc.—The district is drained by the River Tave and its feeders, which have hollowed out for themselves numerous deep valleys and dingles. The general direction of these valleys

is across the strike, and they have thus cut up the country into a series of ridges and hummocky hills, few of which reach an altitude of 600 feet. These dip-valleys afford numerous rock-exposures, but none too many to enable the geologist to interpret so complex a structure with any degree of confidence.

The peculiar hollow extending west of Caermarthen by way of Llanllwch traverses the whole length of the district with a few slight variations, falling in with the Tave Valley west of St. Clear's. On the south, the ground rises towards the Old-Red-Sandstone ridge; and on the north it forms a broken upward slope to the high ground, which here may be considered as the eastward continuation of the Prescelly Hills.

(6) Drifts.—On the whole, the country is fairly free from surface-accumulations, such as Boulder-Clay and other drifts. There is some alluvium in the valleys, especially as they approach the sea; but in their upper reaches, where they are generally very narrow, the quantity is practically negligible.

In the vicinity of St. Clear's, some Boulder-Clay and gravel are found. A patch of the former near Morfa-bach is in places impregnated with ferruginous matter, deposited probably by spring-water rising from the underlying pyritous shales. This feature has led to much fruitless endeavour to find coal.

Near Trefanty, Morfa-bach, and Mylet, a considerable quantity of sand and gravel occurs. In a pit near the first-named place there is a fair sample of oblique and contorted bedding.

Gravel is also dug on the high ground north-east of Glyntâf, as well as near Maesgwynne, and at two or three points in the Gynin Valley.

III. The Succession and detailed Description of the Rocks.

Table I.—The Succession in the Northern Limb of the Anticline.

Bala-Caradoc.[1]	(?)...............	Brown-grey mudstones, shales, and grits.
Llandeilo.	*Dicranograptus*-Beds.	Black slaty beds, with *Dicranograptus*. Ashy black shales, with lenticular bands of limestone, containing *Dicranograptus*, *Leptograptus*, etc. Black shales and mudstones weathering buff and yellow, containing graptolites and trilobites. Black shales, with crowds of *Diplograptus* and shells.
	Asaphus-tyrannus-Beds.	Ashy beds and sandy flags, with *Asaphus tyrannus*, etc.
Llanvirn.	*D.-Murchisoni* Beds.	Striped gritty flags, with abundance of *Didymograptus Murchisoni*. Blue-grey ash, weathering rusty brown. Soft mudstones, with crowds of *Didymograptus Murchisoni*.
	D.-bifidus Beds.	Shales, mudstones, and bands of ash, with graptolites and trilobites.

[1] 'Bala-Caradoc' includes beds of the Shropshire type and Sedgwick's 'Upper Bala.'

TABLE I. (*continued*).

ARENIG	*Tetragraptus*-Beds.	Blue-black shales and mudstones containing *Tetragraptus* and trilobites. Striped flaggy shales, with *Ogygia marginata*, etc. Gritty beds, with *Dictyograptus* and *Dendrograptus*. *Orthis*-mudstones. Grits and conglomerates, with *Orthis* and trilobites. Black ashy shales, with local bands of blue ash. Blue-black shales, with few fossils.

TABLE II.—THE SUCCESSION IN THE SOUTHERN LIMB OF THE ANTICLINE.

LOWER LLANDOVERY		Grey sandstones and flags, with black mudstone-partings—very few fossils. Grey grit and conglomerate.
BALA-CARADOC	Slade Beds.	Blue-grey mudstones, with bands of shelly limestones—usually rotten.
	Redhill Beds.	Blue-grey mudstones, with trilobites and brachiopods (*Trinucleus seticornis*, etc.).
	Sholeshook Beds.	Arenaceous limestones, with many fossils.
	Robeston-Wathen Limestone.	Black limestones, with calcareous shale-partings.
	Dicranograptus-Shales.	Black shales, with graptolites, etc.
LLANDEILO	*Asaphus-tyrannus* Limestone.	Black limestones, with *Asaphus tyrannus* and *Ogygia Buchii*.
LLANVIRN	*D.-Murchisoni* Beds.	Black mudstones, with *Didymograptus Murchisoni* (?).
	D.-bifidus Beds.	Black shales and mudstones, with bands of ash, and containing *Didymograptus bifidus*, etc.
ARENIG	*Tetragraptus*-Beds.	As in Table I.

(*a*) Arenig Rocks.

These are the oldest rocks exposed within the area, and occupy a belt of ground extending from Banc-y-felin on the east, to Login on the west. East of the Fenni Valley the ground is generally low—being part of the peculiar hollow referred to on p. 602, but to the west the ground is more hilly and broken. This variation is accounted for, principally by a difference in the character of the deposits. The beds in the lower ground consist almost entirely of shales and mudstones, while in the high ground west of the Fenni there is a considerable development of grits and conglomerates.

The shales and mudstones are usually black and iron-stained. The staining varies from deep chocolate to iridescent black. Concretionary structure is very common; and, on splitting, the surfaces of slabs present numerous wavy concentric lines of light and dark tints. This characteristic feature is a very useful means

of recognizing the beds in the absence of fossils—and these are generally very scarce. Without some such guide, it would be often impossible to distinguish these beds from others higher in the succession.

The grits and conglomerates west of the Fenni vary considerably in thickness, colour, and texture. All the evidence available points to their being a local development in the *Tetragraptus*-Beds, and there are strong reasons for believing that their real is much greater than their apparent extent, for they have been subjected to much folding and faulting. One very noticeable feature which they present is that they are exposed on the higher ground much more extensively than in the valleys—capping the hills in gentle folds which do not often reach the lower ground.

(1) The Lowest Shales.—The lithological character of the very lowest beds is that of the usual *Tetragraptus*-Shales of the district, but they contain fossils very sparingly, so sparingly that it is difficult to fix their age definitely. In the absence of sufficient proofs to the contrary, they are here placed at the base of the Middle Arenig—or *Didymograptus-extensus* zone.

These shales are well and abundantly exposed in the neighbourhood of Whitland Abbey. They are seen all along the road leading from that place to Pass-by Cottages on the north-west. They contain very few fossils here, and those that do occur are in a very fragmentary state. Among others are trilobites—probably *Æglina*, a *Palæarca*, and an *Orthoceras*. Similar beds are seen at Cwmfelin-boeth, near the small bridge on the Whitland road. These have yielded an *Orthoceras*, a *Trinucleus*, and some small fragments of an unidentifiable graptolite. The blue-black mudstones in the quarry on the roadside a short distance farther south, undoubtedly belong to the same series. Some trilobite-fragments have been collected here, but were so badly distorted that only with hesitation could they be assigned to the genus *Æglina*.

These beds also come to the surface at frequent intervals in the valley of the Gronw, and here they have yielded some extensiform graptolites a little to the north of the Old Cottage, north-east of Llwyngwydd. The graptolites here are associated with *Orthoceras* sp., *Caryocaris*-tails, and *Orthis Carausii*, Salt. A few graptolite-fragments were collected also from the small section immediately south of Penyglog, and were associated with *Æglina*, *Theca*, and *Orthoceras*.

Certain shales are abundantly exposed near Pantgwyn and Aberdauddwr in the Nantclomendy valley. Some of them undoubtedly belong to this horizon, but whether those occurring in Aberdauddwr farmyard are of this age may be questioned. As regards texture and colour, these are much like the Upper *Tetragraptus*-Beds; but graptolites, though present, are very scarce and fragmentary. Other fossils collected here are :—*Æglina* sp., *Trinucleus* sp., *Agnostus* cf. *M'Coyii*, Salt., *Beyrichia*, *Orthis* cf. *Menapiæ*, Hicks, and *Lingula* sp.

(2) Ashy Mudstones, etc.—Passing upwards, the blue-black shales become coarser in texture, and take on the character of ashy mudstones, becoming gritty as they near the base of the grits. They are sparingly fossiliferous, except in some bands in which specimens of *Orthis Carausii*, Salt. are fairly numerous. They yield a few dendroid graptolites—the forerunners of the great profusion which was to appear later. Within these beds are several igneous bands, some of which attain a thickness of between 3 and 4 feet. These are best seen in the old quarry on the brow of the hill north-east of Blaenweneirch. They are also seen in an old quarry on the roadside about 100 yards to the west. Here the mudstones have yielded several specimens of dendroid graptolites, but nothing else. This bit of ground has been disturbed by faulting, and the structure is difficult to make out. The ash-bands with their associated striped mudstones are traceable for some distance westward, and surface-evidence suggests that they have been disturbed by two faults before they reach the vicinity of Pantyffynnon Farm, where they are cut off altogether.

East of the first-mentioned quarry these beds are traceable down the slope with a north-easterly strike due to dip, and are seen in the bed of the stream. They are again observed along the Blaencediw Lane east of the dingle. Here the dips indicate a small anticline, for, where the beds are last seen in place in a small quarry, they dip southward at about 45°. Near this point they are cut off by an east-and-west fault—probably a thrust. This igneous band has not been seen anywhere else in the district.

(3) Grits with *Orthis* and Trilobites.—The grits, as stated above, are very variable, both in thickness and in texture. They are more or less ashy in some localities, and again at no great distance they assume the character of coarse conglomerates. This variation is accompanied by a rise and fall in the number, as well as by a change in the character, of the fossils.

These beds, again, are well represented in the neighbourhood of Whitland Abbey, where grits have been extensively quarried. They form the crest of the ridge that separates the valleys of the Gronw and Fenni from near the Abbey to Penyglôg. Fossils occur only in certain thin bands, and these are seldom exposed. Trilobite-fragments and a few specimens of *Orthis* have been collected near the last-named place, and near Pantyderi, as well as at several points in the Gronw Valley.

There is, behind the Abbey mansion, a peculiar tump rising more than 100 feet above the valley-floor. This is made up largely of grits and thick beds of coarse conglomerate, but they are much disturbed by faulting—several fractures being visible in section. The displacement, however, cannot be great. A short distance to the north there are two outcrops, and quarries have been opened in both. The dips here indicate a shallow synclinal fold. Fossils are very rare in these—fossil-bearing bands, presumably, not being exposed at this point. North of Pound glas in the immediate

neighbourhood, however, where some members of the series are found, fossils are very common. These beds, which here consist of bands of grit alternating with shales, are well seen striking across the road immediately north of the farm, and trilobite-fragments and *Orthis* are fairly abundant both in grits and shales. Heads and tails of *Ogygia marginata* are met with, and *Orthis Carausii* (Salt.) is common.

There are apparently three isolated patches of these grits in the neighbourhood of Pound-glâs and Llwyngwydd, in which several small quarries have been opened. Their presence is indicated by the abundant loose débris and the character of the soil. The small quarry in the wood north-east of Llwyngwydd shows these grits dipping under higher beds.

Another isolated patch of these grits caps the hill south of Pass-by, and a quarry has been opened in them at Pencilpost. The coarsest bed here has yielded an *Orthis*; a few trilobite-fragments and bits of dendroid graptolites have also been found here. Some of the beds crop out with a southerly dip, at the bend in the old lane north of Pencilpost, and here they are fairly crowded with fossils, including a large *Lingula*, *Ogygia* cf. *marginata*, Crosf. & Skeat, *Trinucleus* cf. *Sedgwickii*, Salt., *Orthis Carausii*, Salt., *O. Menapiæ*, Hicks, etc.

The hollow between this section and Pass-by Cottages is in shale; but immediately north of the Cottages the grits are again seen striking across the road with a northerly dip, and containing fossils of the usual type. The abundant débris along the crest of the hill to the north, extending from Cwmfelin-boeth to Nant-clomendy Dingle, indicate their presence and strike, and small quarries have been opened in these grits in several places. They are seen passing under higher beds at Cwmfelin, where they have been considerably disturbed. A fault of some magnitude is seen in a quarry on the west of the valley, and its effects are shown behind a cottage on the east side also. This fault probably accounts for the non-appearance of the grits in the Nant-clomendy dingle.

Farther north are two outcrops of the same series of beds. One extends from a point a little north of Aberdauddwr, where it is exposed in a small quarry in gorse-grown ground, to another point a little west of Pantyffynnon. They are seen crossing the stream by the Old Cottage in the dingle—east of Blaenweneirch, and passing westward they form the feature south of that place. They also form the hog-backed ridge west of Pantyffynnon. Some of them are seen in the yard at that place, where they and their associated beds show signs of considerable disturbance. North of Aberdauddwr they have yielded *Orthis Carausii*, Salt., and *Dendrograptus*-fragments. South of Blaenweneirch similar fossils occur.

The other and northernmost outcrop, a little farther north, is more extensively developed, and is slightly different in character. The beds are exposed in the dingle east of Blaencediw—200 yards or so below the springs. Many small quarries have been opened in them in the immediate neighbourhood—one at the bend in the

lane and another in the dingle to the north-west. They are traced westward across the hill north of Blaenwencirch, and have been extensively quarried for road-metal on the side facing Henllan-Amgoed. Some of the beds here, as well as at Blaencediw Quarry, are crowded with *Orthis Carausii*, Salt. Occasional trilobite-fragments have also been found here. At this quarry the fossil-bearing bands weather buff and mottled grey.

A short distance south of the quarry these beds appear to be faulted-out, and are not seen in the dingle to the west; but on the small ridge south of Henllan Church they come to the surface again, and the lower beds are exposed in a quarry at the southern extremity of that ridge. Few fossils occur here, consisting of *Orthis Carausii*, Salt., and doubtful fragments of *Dendrograptus*.

Along the western flank of this ridge the grits disappear, partly by faulting, and partly by passing under higher beds.

(4) *Orthis*-Mudstone and *Dictyograptus*-Beds.—At Blaencediw Quarry the grits are seen passing up into gritty black mudstones abounding in *Orthis Carausii*. Some hard bands in these are crowded with graptolites of *Dictyograptus* and *Dendrograptus* types. A small collection of fossils from this section was submitted to Miss G. L. Elles, D.Sc., and she identifies the following:—

Callograptus radiatus, Hopk.
Callograptus Salteri, Hall.
Callograptus Salteri, var. *attenuatus*, Elles MS.
Dictyograptus cf. *Homfrayi*, Hopk. (possibly new).
Dictyograptus Homfrayi, Hopk.
Climacograptus implicatus, Hopk.
Dendrograptus flexuosus, Hall.
Dendrograptus sp. (possibly new).
Orthis Carausii, Salt.
Lingula sp.

There are several faults in this quarry, but none appears to be of great extent.

Farther up the dingle, the beds become more flaggy, and gradually change their texture, passing up into finer-grained mudstones with *Tetragraptus* at no great distance. These flaggy beds contain *Callograptus*, etc., in abundance.

Orthis-mudstones come to the surface on the road near Penlanfach, where they are fairly fossiliferous, but they have not yielded anything besides *Orthis Carausii*, Salt. Farther south, flaggy beds are seen on the roadside lying nearly horizontal. These have yielded an *Orthoceras* sp. (possibly new), *Lingula* sp., *Ogygia marginata*, *Trinucleus* sp., *Siphonotreta (?)*, etc.

There is a good section of black shales and mudstones along the lane leading to Henllan grit-quarry. The beds are somewhat flaggy in places, but are disappointing as regards their fossil contents. In the lower part of the road there are some lenticular masses of weathered grit packed with *Orthis Carausii*, Salt.: *Orthoceras* sp., *Theca* sp., and some obscure dendroid forms also occur.

Higher in the series are some shales and flags rich in trilobites.

These beds are well exposed east of the ford at Rhydhenllan—up the hill towards Llwynderw—near the mill—and on the road immediately south of Henllan Church: they have yielded:—

Dendrograptus sp.	*Orthis Carausii*, Salt.
Callograptus sp.	*Orthis Menapiæ* (?) Hicks.
Ogygia marginata, var.	*Siphonotreta* sp.
Ogygia Selwynii, Salt.	*Obolella* sp.
Trinucleus sp.	*Lingula* sp.
Ampyx sp.	*Orthoceras* sp.
Æglina sp.	*Theca* sp.

Beds of the same age occur at Blaenweneirch, and they have yielded *Ogygia marginata* var. and *Callograptus Salteri* var. *attenuatus* Elles (MS.). They are also seen in the dingle east of Blaenweneirch, but have not yielded any fossils there.

The grits of Cwmfelin-boeth pass up into gritty mudstones seen on the road south of the entrance to Llangan Vicarage (Talvan). These beds are very unfossiliferous, and have yielded only a few fragments of dendroid graptolites too imperfect for identification. However, there is no reason to doubt that they are what they appear to be from their position.

Mudstones of the same type occur near Penyglôg, Cefnmeurig, Llwyntreharn, and Pistyllgwyn, all of which have yielded fragments of dendroid graptolites, and occupy a similar position in relation to the grits.

(5) *Tetragraptus*-Beds.—The lane leading up to Cilhenrhôs from Rhydhenllan, exposes a continuous section in shales and mudstones, showing the *Ogygia-marginata* Beds passing up to *Tetragraptus*-Shales. Near Llebach a roadside-exposure in blue-black shales has yielded *Tetragraptus quadribrachiatus*, Hall, *T. Headi*, Hall, *Didymograptus extensus*, Hall, *Æglina* (?) *binodosa*, Salt., *Trinucleus* sp., *Theca*, etc.

Similar beds are seen near Henllan Farm, but here fossils are generally scarce. About Penyback, on the western side of the dingle, beds of the same age are frequently exposed, but fossils rarely occur.

Along the hill between Gellidiogyn lane and Cadwgan, shales are continuously exposed, but fossils occur sparingly in them. Their general character, however, is such as to render their identification as *Tetragraptus*-Beds fairly certain. Beds of the same horizon are also abundantly exposed on both sides of the dingle east of Gellidiogyn. Fossils have been collected at several points between Castell-draenog and Blaencediw, especially along the west side of the ridge. The beds consist chiefly of blue-grey mudstones and shales, and their fossil contents include:—

Tetragraptus Headi, Hall.	*Æglina* sp.
Tetragraptus Amii, Lapw.	*Trinucleus Sedgwickii*, Salt.
Didymograptus patulus, Hall.	*Orthis calligramma*, Dalm.
Dichograptus sp.	*Lingulella* sp.
Æglina binodosa, Salt.	

The roadside-exposure at the entrance to Llangan Vicarage is presumably the 'north of Talvan' locality of the late Thomas Roberts. These beds succeed the gritty mudstones mentioned above, apparently without a break, and this agrees with the succession elsewhere. The fossils collected here include the following, most of which were recorded by Mr. Roberts:—

Dictyograptus sp.
Dendrograptus sp.
Didymograptus nitidus, Hall.
Didymograptus patulus, Hall.
Tetragraptus Headi, Hall.
Tetragraptus serra, Brongn.
Callograptus Salteri, Hall.
Callograptus persculptus, Hall.
Dichograptus sp.
Æglina sp.
Trinucleus Sedgwickii, Salt.
Orthis calligramma (?) Dalm.
Palæarca.
Obolella.

The old lane at Pontygraig, east of Trefach, cuts through the same beds, which contain a fair number of fossils. Among others, the following occur:—*Didymograptus extensus*, Hall: *D. patulus*, Hall; *Tetragraptus Amii*, Lapw.; *Dendrograptus* sp.; *Æglina*, and other trilobite-fragments.

The old road-section at Penparc-uchaf is in shales of the same age, and fossils are fairly abundant, especially graptolites. The following were collected:—

Didymograptus extensus, Hall.
Didymograptus sparsus, Hopk.
Didymograptus patulus, Hall.
Didymograptus nitidus, Hall.
Tetragraptus Headi, Hall.
Tetragraptus Bigsbyi, Hall.
Dendrograptus sp.
Dictyograptus sp.
Dichograptus sp.
Several species of small trilobites and an *Orthis*.

Extensiform graptolites have been collected at Pwllyrhwyaid and Foxhall, north of Whitland.

In the old quarry north-east of Llanlliwe there are some thickly-bedded mudstones, with the beds almost vertical and much crushed. Some bedding-planes are covered with graptolites, but the material crumbles to pieces on being handled, making it difficult to secure a good identifiable specimen. Some large trilobites also occur here, but they are much distorted and broken. Among the graptolites the following have been made out:—*Didymograptus extensus*, Hall; *D. nitidus*, Hall; *Tetragraptus Headi*, Hall; *T. Bigsbyi*, Hall; and *Dichograptus* sp.

The shales at Sarnlâs near Llangan Church, though abundantly exposed, contain few fossils. Those that do occur lead to the conclusion that these beds are at the top of the *Tetragraptus*-series, or at least very near the top. The fossils include fragments of *Didymograptus (?) hirundo*, Salt.; *Diplograptus dentatus*, Brongn.; *Climacograptus confertus*, Lapw.; *Æglina* sp.; *Obolella plumbæa*, Salt.

There are also numerous exposures of shales at Blaenwernddu. These present the characteristic weathering of the *Tetragraptus*-Beds, but fossils occur very sparingly. The specimens found are

of the *Didymograptus-extensus* type. The beds are probably the same as those exposed north of Talvan.

About three-quarters of a mile to the west the same beds are seen in some roadside-sections. That near Rhydywrach has yielded *Didymograptus extensus*, Hall; *Tetragraptus serra*, Brongn.; *Æglina* sp.; *Obolella* sp., etc. There is some obscure faulting in the locality, for immediately to the south are *Didymograptus-bifidus* Beds, which appear to dip under *Tetragraptus*-Beds. Also, at a short distance to the north, there are shales of *D.-bifidus* type.

The Rhydywrach stream, to the south, has cut through shales and mudstones at several points. Fossils have been collected in these, which fix their age as Upper *Tetragraptus*; and their general strike and dips suggest that they pass up into higher beds in the immediate vicinity.

In the railway-cutting north of Llanfallteg Station are seen good sections in *Tetragraptus* and *Didymograptus-bifidus* Beds, with a fair abundance of characteristic fossils. The dips at the southern end of the section suggest a small anticlinal fold showing Upper-*Tetragraptus* passing up into *Didymograptus-bifidus* Beds. The former here contain a fair abundance of *Diplograptus dentatus*, Brongn., and *Climacograptus confertus*, Lapw.: *Didymograptus patulus*, Hall; *D. hirundo*, Salt.; but no *D. bifidus*. Trilobites also occur, including *Barrandea* sp., *Æglina binodosa*, Salt., and *Æglina* sp.; and *Conularia*, *Theca*, and *Orthoceras* have been obtained. The beds in this section have been disturbed by several faults—probably the westward continuation of Rhydywrach conditions.

North of the small dingle (the southernmost of the two) the beds have yielded the following fossils:—

Dendrograptus sp.	*Tetragraptus quadribrachiatus*, Hall.
Schizograptus sp.	*Æglina* sp.
Didymograptus extensus, Hall.	*Trinucleus Sedgwickii*, Salt.
Didymograptus patulus, Hall.	*Lingulella* sp., etc.
Tetragraptus serra, Brongn.	

The same series of beds—mudstones and shales—are exposed at intervals along the railway near Gwarmacwydd, and continue northwards as far as Login, but are very sparingly fossiliferous. Even where fossils occur they are not easy to find, and then to identify, owing to cleavage.

There is a continuous section up Penclipin Hill and down Mount-Pleasant Hill, in both of which fossils are exceedingly scarce. The beds at Mount Pleasant are more arenaceous than the usual type, are badly cleaved, and have not yielded a trace of fossils. These beds are also exposed about Bryntâf and Penyrallt.

East of the Gronw at Glandwr, near Pantygrug, there are several exposures of graptolitiferous shales and mudstones, which have yielded *Didymograptus extensus*, Hall; *Tetragraptus quadribrachiatus*, Hall; *T. Bigsbyii*, Hall; *Schizograptus* sp.; *Æglina* sp.;

Trinucleus sp., etc. The relation of these beds to the grits of the immediate neighbourhood is rather difficult to make out. Taking the evidence of the dips, the most probable interpretation is that the graptolite-beds are folded down here and cut off by a fault immediately to the south.

About $1\frac{1}{2}$ miles to the north, in the gorse-grown ground south of Cilhirwydd, is a small quarry in shales, with some hard bands. The shales contain a fair number of graptolites, but three bedding-planes in one hard gritty band are especially crowded with them: *Didymograptus hirundo*, Salt., and *D. patulus*, Hall, can be recognized. Some trilobites of the genus *Æglina* and a *Lingula* also occur. This exposure is within a short distance of a *Didymograptus-bifidus* ash outcrop.

The late Thomas Roberts reported the occurrence of 'tuning-fork' graptolites at Penycoed, east of Whitland. The shales here are very barren, and from their texture and colour could be taken for *Tetragraptus*-Beds; further, at Nant-yr-ailwyn, close by, shales of exactly the same character are fossiliferous, and have yielded *Didymograptus (?) hirundo*, Salt.; *D. patulus*, Hall; *D. gibberulus*, Nich.; *Lingula*; and *Palæarca*. (It may be suggested that Penycoed near Mydrim was meant, for at that place tuning-fork graptolites do occur.)

The shales in the bed of the stream south of Nant-yr-allwyn Bridge have yielded extensiform and dendroid graptolites in several localities. Extensiform graptolites have also been collected near Tynewydd (east of Whitland), and at Forest.

East of the River Fenni the beds are abundantly exposed, but, as elsewhere, are sparingly fossiliferous except in certain localities. The old quarry at Llwyncrwn has yielded the greatest variety of fossils. Here some bands are crowded with graptolites, the following having been collected and identified:—

Didymograptus extensus, Hall.
Didymograptus nitidus, Hall.
Didymograptus patulus, Hall.
Didymograptus sparsus, Hopk.
Didymograptus hirundo, Salt.
Tetragraptus serra, Brongn.
Tetragraptus Amii, Lapw.
Tetragraptus Bigsbyii, Hall.
Callograptus Salteri, Hall.
Callograptus sp.
Dendrograptus persculptus, Hopk.
Dendrograptus flexuosus, Hall.
Dendrograptus sp.
Ptilograptus Hicksii, Hopk.
Dictyograptus cf. *cancellatus*, Hopk. (possibly new).
Dichograptus sp.
Asaphus sp. (large and possibly new).
Æglina caliginosa.
Æglina sp.
Trinucleus cf. *Sedgwickii*, Salt.
Orthis sp.
Lingula cf. *petalon*, Hicks.
Obolella sp.
Siphonotreta.
Conularia.
Theca.
Orthoceras cf. *sericeum*, Salt.
Caryocaris; etc.

At Pont-y-fenni, two-thirds of a mile due south, shales and mudstones are exposed in several good sections. In the old quarry above the bridge there seems to be a slight displacement. Highly-

slickensided slabs have been dug up about the middle of the quarry, and south of this spot the following fossils occur :—

Didymograptus extensus (?) Hall.	*Agnostus* sp
Didymograptus pennatulus, Hall.	*Lingula*.
Didymograptus patulus, Hall.	*Obolella*.
Tetragraptus serra, Brongn.	*Palæarca*.
Tetragraptus quadribrachiatus, Hall.	*Conularia margaritifera*, Salt.
Ampyx cf. *Salteri*, Hicks.	*Conularia* cf. *Homfrayi*, Salt.
Æglina caliginosa, Salt.	*Theca* sp.
Æglina cf. *boia*, Hicks.	*Caryocaris* sp.
Trinucleus sp.	*Orthoceras* sp.; etc.

North of the break there is a slight lithological difference, and the fossils indicate a higher horizon, probably the higher beds of the *Tetragraptus*-Series. The following fossils have been found :—*Diplograptus dentatus*, Brongn.; *Climacograptus confertus*, Lapw.; *Placoparia cambrensis*, Hicks; and a few fragments of extensiform graptolites, but no *Didymograptus bifidus*. The roadside-sections have yielded *Didymograptus* cf. *extensus*, Hall; *D. patulus*, Hall; *Tetragraptus serra*, Brongn.; *Conularia* sp.; *Bellerophon multistriatus*, Salt.; and an *Orthoceras*.

Extensiform graptolites have been collected from the mudstones in the watercourse south of Bwlchydommen. *Æglina* and other trilobite-fragments also occur here, near the junction of the *Tetragraptus*-Beds and the *Didymograptus-bifidus* Beds.

The dips here strongly suggest an inversion due to overfolding or faulting—probably to both. The crushed state of some black shales seen in a ditch west of Sabulon, and the watery condition of the ground near by, confirm the suggestion as to the occurrence of a fault.

The mudstones in Gors farmyard have yielded some isolated *Tetragraptus*-stipes, and the exposures about Pwlltrap contain few fragments of *Dendrograptus* and *Æglina*. A *Dictyograptus* was obtained from a well at Ostrey, and fragments of *Didymograptus hirundo*, Salt., from the mudstones in the bed of the Gynin close by. Some fragments of extensiform graptolites have been collected from the crushed mudstones at Melin Cleifon and the railway-cutting near St. Clear's Station. *Æglina* also occurs at the latter place.

A small opening in shales at Parkyrabat and the roadside-section near Castell-y-waun have yielded graptolites of *extensus*-type. The latter locality has, in addition, yielded a crushed specimen of *Tetragraptus* cf. *quadribrachiatus*, Hall; *Didymograptus extensus (?)* Hall; and tails and eyes of *Æglina* have been collected from the mudstones of the railway-cutting north of Banc-y-felin.

Near Llainlwyd, a mile north of St. Clear's Station, there is a good road-section in shales. These are fairly fossiliferous at certain points. At the lowest end of the section the beds are nearly vertical and barren, but at the turning in the road higher up extensiform graptolites occur, which are usually very fragmentary. Half way up the hill the following have been collected :—

Didymograptus extensus, Hall.	*Ampyx* sp.
Didymograptus patulus, Hall.	*Trinucleus* cf. *Salteri*, Hicks.
Tetragraptus Amii, Lapw.	*Æglina binodosa*, Salter (large).
Tetragraptus serra, Brongn.	*Palæarca* sp.; etc.

Still higher up, at Tynewydd, some mudstones dug out of a well were crowded with *Didymograptus extensus*, Hall. Associated with these were *Barrandea* sp.; *Trinucleus* cf. *Murchisoni*, Salter; *Illænus* (?); *Lingula* sp.; *Palæarca*, etc. *Didymograptus-bifidus* Beds are exposed a few yards farther north; and it is almost a certainty that the junction is a faulted one, and that a portion of both series has been cut out here.

(6) Conclusions.—Reviewing the stratigraphical and fossil evidence, the conclusion is reached that the Arenig rocks of this district are the equivalents of the *Tetragraptus*-Beds of St. David's and are of Middle and Upper Arenig age. There is not sufficient evidence to prove that the Lower Arenig rocks are represented in Western Caermarthenshire.

The Middle Arenig strata (the equivalent of Hicks's 'Lower Arenig') here naturally divide themselves into two sub-groups—(*a*) the Blaencediw *Dictyograptus*-Beds with their associated grits, and the Henllan Trilobite-Beds; and (*β*) the higher shales and mudstones with *Tetragraptus* and *Didymograptus extensus*, etc.

The Upper Arenig of this district includes all other beds with *Didymograptus hirundo*, and other extensiform graptolites, up to and including beds with *Diplograptus* and *Climacograptus* without *Didymograptus bifidus*.

The complexity of the ground is such, that no attempt has been made to draw definite lines separating the Upper from the Lower Arenig rocks of the district.

(*b*) Llanvirn Group: *Didymograptus-bifidus* Beds.

The *D.-bifidus* Beds of the district consist of a series of blue-grey and blue-black mudstones and shales, thin grits, and bands of ash. The mudstones and shales are often stained light chocolate. They weather in irregular patches of light buff and fawn, and when viewed edgewise they present an irregular streaky appearance. Where they are cleaved they assume a peculiar sheeny lustre, probably due to shearing. The grits are blue-grey in colour and much jointed. The ashes, freshly fractured, are light blue, but on weathering they present a buff or cream-coloured groundmass with specks of rusty material, formed probably by the decomposition of pyrites and other minerals containing iron. Some of the weathered beds are quite vesicular, owing to the decomposition of minerals containing lime. Calcareous pea-like masses are found in half-weathered samples.

The rocks have been subject to a great deal of folding and faulting, and the beds are frequently repeated, the ash-bands suffering with the rest. There are, however, at least two distinct

bands of ash. Cone-in-cone structure is very common in the grit-bands, as well as in nodules embedded in the mudstones and shales; this is especially the case in the neighbourhood of St. Clear's.

Beds of this age occupy a considerable space, both north and south of the *Tetragraptus*-belt.

(1) The Southern Outcrops.—These beds are much in evidence at St. Clear's. The main road cuts through them at Blue Boar, and there is a good section up the hill leading to Lower St. Clear's. This latter exposure shows the disturbance mentioned above (p. 613). There are good sections also in the old lane near Croft Lodge, and along the Cliff, where the *Didymograptus-bifidus* Beds are faulted against black *Dicranograptus*-Beds.

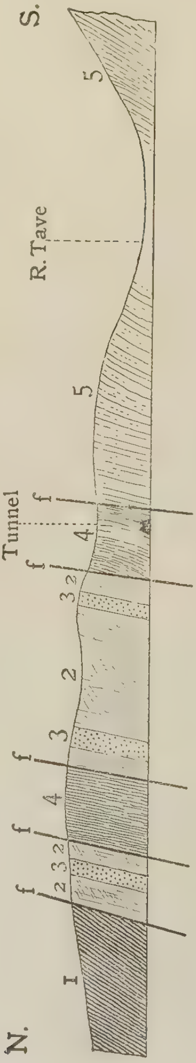


Fig. 3.—*Section from north to south, near Forest, on the scale of 6 inches to the mile. (Marked on the map, Pl. XLVI, as 'Section III.')*

1 = *Tetragraptus*-Beds.
2 = *Didymograptus-bifidus* Beds.
3 = *Didymograptus-bifidus* Ash.
4 = Slade Beds.
5 = Lower Llandovery (?).
f f = Faults.

The general dip about here suggests an overfold from the north, as *Didymograptus-bifidus* shales appear to pass under older beds. This is the case not only here, but all along the strike. Fossils are fairly common. The main-road section and that in the 'old lane' are perhaps the best places for collecting.

The following occur on the main road:—

Didymograptus bifidus, Hall.
Didymograptus euodus (?) Lapw.
Didymograptus Nicholsoni, Lapw.
Didymograptus Nicholsoni, var. *planus*, Elles & Wood.
Agnostus M'Coyi, Salter.
Æglina binodosa, Salt.
Æglina (young?).
Calymene parvifrons, Salt.
Placoparia cambrensis, Hicks.
Illænus Hughesii, Hicks.
Orthoceras cf. *caereesiense*, Hicks.
Theca sp.
Conularia sp.
Ophileta.
Bellerophon multistriatus (?) Salt.

The 'old lane' has yielded the above, and also the following:—*Didymograptus (?) geminus*, His.; *Phacops llanvirnensis*, Hicks; *Bellerophon* sp. (young?).

East of St. Clear's, at Plasygwyr and Bronheulog, these mudstones are associated with a series of

harder arenaceous beds. The softer material contains *Didymograptus bifidus*, Hall, and *D. Nicholsoni*, var. *planus*, Elles & Wood. *D. bifidus*, Hall, as well as *Dinobolus Hicksii*, Dav., occurs in the shales on the roadside west of Asgood.

The old quarry near Danrallt has also yielded a fair number of fossils, including *Didymograptus bifidus*, Hall; *D. indentus*, Hall; *D. Nicholsoni*, Lapw.; *Diplograptus dentatus*, Brongn.; *Climacograptus confertus*, Lapw.; *Illænus Hughesii*, Hicks; and *Barrandea Homfrayi*, Hicks. The beds here are nearly vertical, and contain some hard bands.

West of St. Clear's the beds are much exposed in road-sections and otherwise. The road-section at Llaindelyn, south of Pwlltrap, is on the line of the Timber-Yard disturbance, and the mudstones here have yielded:—

Didymograptus bifidus, Hall.	*Phyllograptus anna*, Hall.
Didymograptus indentus, Hall.	*Æglina binodosa*, Salt.
Diplograptus dentatus, Brongn.	*Bellerophon (?) multistriatus*, Salt.
Phyllograptus typus, Hall.	*Orthoceras* cf. *encrinale*, Salt.

Didymograptus bifidus has been collected at Heol-cerrig, several localities on the Backé, and in the dingle between the Woolston-Ash ridge and Castle Hill. Some 'mining' (*sic*) operations have been carried on in this dingle, the blackness of the shales being thought a certain indication of the occurrence of coal. Several pits were sunk here, and the débris has yielded *D. bifidus*, Hall, in fair numbers.

A short distance north of Clôg-y-frân two other pits have been sunk in similar beds, one of which is within a few yards of the fault which here cuts off the *Asaphus-tyrannus* Limestone. Reference has already been made to *Didymograptus-bifidus* Beds in Clôg-y-frân farmyard. The beds are fairly fossiliferous; and *D. bifidus*, Hall, *D. indentus*, Hall, *Æglina binodosa*, Salt., *Æglina* sp., *Barrandea* cf. *Homfrayi*, Hicks, and *Bellerophon* have been collected here.

There are two outcrops of *Didymograptus-bifidus* rocks in the vicinity of Forest, separated by a slice of Upper Bala Beds, and the southern outcrop is again faulted against beds of the same age near the tunnel. Fossils are exceedingly scarce, only a few specimens of *Climacograptus* having been found, and all of them in one locality. Had it not been for the ashes, of which there are three well-developed bands here, it would be difficult to recognize the beds with any degree of certainty.

West of Forest, the beds seem to be cut off entirely by a fault which appears to bring Bala Beds against Arenig. It cannot be made out exactly what takes place for some distance west, for the ground is obscured by alluvium. But, in the neighbourhood of Whitland, *Didymograptus-bifidus* Beds again occupy a considerable space. *D. bifidus* has been collected from a roadside exposure 100 yards north of the Intermediate School. The dips up this

hill vary a great deal in inclination, but are always northward, both in the *Didymograptus-bifidus* and in the Arenig Beds exposed here. From this fact it may be inferred that the overfold indicated at St. Clear's is continued thus far west. The beds are also seen at Middleway, and up the Llwynbrain Hill, where they are faulted against beds of Lower Llandovery (?) age: fossils are, however, rare, consisting of an occasional fragment of graptolite or trilobite. They are exposed abundantly in the lane leading up the hill from Trevaughan. The ashes come out on this hill, and huge boulders are profusely scattered about. Ash-débris is traceable eastward along the brow of the hill for some distance, but then ceases abruptly, owing, presumably, to the beds being cut off by a fault, or to their being overlapped by the Old Red Sandstone. There is certainly some faulting here, but the paucity of good sections renders the structure difficult of interpretation.

The only fossil-locality of any value hereabouts is on Gallt-y-beili Farm, south of the Tave, and nearly opposite the railway-station. This section has yielded:—

Didymograptus bifidus, Hall.	*Trinucleus* cf. *Murchisoni*, Salt.
Didymograptus indentus, Hall.	*Barrandea Homfrayi*, Hicks.
Diplograptus dentatus, Brongn.	*Orthis* sp.
Æglina sp.	*Obolella (?) plumbea*, Salt.
Illænus Hughesii, Hicks.	*Bellerophon*; etc.

This outcrop runs westward into Messrs. Marr & Roberts's ground, and possibly some distance up the valley of the Tave, but there are no exposures here.

In the neighbourhood of Llanfallteg, however, is another small area occupied by these beds. A railway-section immediately northwest of the Rhydywrach stream has yielded *Didymograptus bifidus*, Hall, and *Trinucleus* cf. *Etheridgii*, Hicks. A small quarry in mudstones, 100 yards or so north of Llanfallteg Station, has produced a fairly-good series of fossils, including:—

Didymograptus bifidus, Hall.	*Climacograptus* cf. *confertus*, Lapw.
Didymograptus Nicholsoni, Lapw.	*Glossograptus (?)*.
Didymograptus affinis, Nich.	*Phacops llanvirnensis*, Hicks.
Didymograptus sp.	*Barrandea Homfrayi*, Hicks.
Diplograptus dentatus, Brongn.	*Theca*.

Mudstones at Penybont, west of the Tave, have yielded *Didymograptus bifidus*, Hall, and *Ampyx* cf. *Salteri*; and at Bwlchmelyn similar beds occur, where *D. bifidus* and an *Æglina* have been collected. The beds here have been somewhat disturbed, especially west of the well, but the dips are generally low.

About a mile to the east is Rhydywrach, where there are several exposures of shales and mudstones. That in the yard at Cefnmaen-llwyd is particularly rich in fossils. The beds here are very soft and of a light colour, the weathered portions being light fawn.

Some bands are crowded with graptolites. Trilobites also are fairly numerous. The following fossils occur :—

Didymograptus bifidus, Hall.
Didymograptus Nicholsoni, Lapw.
Didymograptus Nicholsoni var. *planus*, Elles & Wood.
Didymograptus affinis, Nich.
Didymograptus acutidens, Lapw.
Diplograptus dentatus, Brongn.
Climacograptus teretiusculus, His.
Climacograptus confertus, Lapw.

Phacops llanvirnensis, Hicks.
Barrandea Homfrayi, Hicks.
Æglina sp.
Illænus Hughesii, Hicks.
Placoparia cambrensis, Hicks.
Calymene parvifrons, Salt.
Ophileta.
Bellerophon; etc.

(2) The Northern Outcrops.—The *Didymograptus-bifidus* Beds on the north of the anticline differ lithologically, to some extent, from their equivalents on the south, and (taken altogether) they are not so fossiliferous. Having been affected more or less by cleavage, the fossils that do occur are neither so easy to find nor so well preserved.

On entering the district on the east, the first or main outcrop extends from Melin-ricket to a point about a quarter of a mile south of Pont-gowyn; and, on reaching the Tave, it occupies the ground between Login and Llanglydwen, a distance of about 3½ miles.

Didymograptus bifidus, Hall, occurs in a small quarry near Penrhiw (Thomas Roberts's 'Penllwyn-bach' locality). Several little quarries have been opened here in one of the ash-bands. *D. bifidus* has also been collected at Pantglâs and Pantybrodyr.

The ground between the Cywyn and the Dewi-fawr has been much cut up by faults which go on splitting westward. This is well shown by the behaviour of the ash-bands (see Pl. XLVI, map).

The road between Plas-parcau and Mydrim affords an almost continuous section across the beds, showing much of their intricate plication. Dips here change their inclination and direction at very frequent intervals. The mudstones at Plas-parcau Quarry have yielded a fair number of graptolites, including *Didymograptus bifidus*, Hall; *D. Murchisoni*, var. *geminus*, His. (or a large *D. bifidus*); *D.* cf. *hirundo (?)*, Salt., etc. There is some obscure faulting in the immediate neighbourhood of this quarry; and, weighing the evidence of the fossils, it may be questioned whether the succession is normal here.

Fossils have also been collected from a roadside section near Penycoed, where *D. bifidus*, Hall, *D. Murchisoni (?)*, Beck, and a several-branched form of graptolite occur. The graptolite-bearing rock here is quite different in character from the usual type of *D.-bifidus* Beds, consisting of thin, hard, flaggy, striped bands embedded in black shales. There is a complication of faults here again, and these beds may not be in their right place, for between this section and the true base of the *D.-Murchisoni* Beds, a little farther north, some indisputable *D.-bifidus* mudstones occur.

D. bifidus occurs in Penwch farmyard, and near Salem Chapel.

The road between Treasgell Gate and the top of the hill exposes a continuous section in shales. Typical *Didymograptus-bifidus* fossils have been collected from the lower part, and the characteristic lower *D.-Murchisoni* Beds are seen coming on about 100 yards from the top. It is worthy of remark that these upper *D.-bifidus* Beds do not include any ash-bands.

Shales and mudstones are extensively exposed along the lane west of Treasgell, and the following fossils occur:—

Didymograptus bifidus, Hall.
Didymograptus Nicholsoni var. *planus*, Elles & Wood.
Didymograptus patulus, Hall.
Diplograptus dentatus, Brongn.
Illænus Hughesii, Hicks.
Trinucleus cf. *Etheridgei*, Hicks.
Barrandea cf. *Homfrayi*, Hicks.
Theca.
Orthoceras cf. *caercesiense*, Hicks.
Lingula sp.; etc.

The shaly mudstones in the small quarry west of Melin-castell have yielded all the above, and in addition a *Placoparia* sp., *Calymene parvifrons*, Salt., and an *Æglina.*

Didymograptus bifidus and fragments of several species of trilobites have been collected from the mudstones on the Castell-gorfod road near Efel-wen. *D. bifidus* also occurs farther north at Mount Pleasant, and at Pensarn west of Cethin, where it is associated with a *Bellerophon* and trilobite-fragments.

Again, farther north near Rhydyceisiaid Chapel there are numerous sections in shales. The exposures on the roadside have yielded *D. bifidus*, Hall; *D. Murchisoni (?)* var. *geminus*, His.; *D. Nicholsoni* var. *planus*, Elles & Wood; *D. patulus*, Hall, or *D. hirundo*, Salt.; *Diplograptus dentatus*, Brongn.; *Climacograptus confertus*, Lapw.; *Barrandea* cf. *Homfrayi*, Hicks; and *Trinucleus* sp. These shales are cleaved, and the fossils are slightly distorted. In shales at Wheel-about, *Didymograptus bifidus* and a six-stiped *Dichograptus* have been found.

The mudstones at Penybont and Penyback are very much cleaved, and the fossils—trilobites chiefly—which occur in them are hopelessly distorted and broken. Farther north and west fossils become very rare. A few graptolite-fragments have been collected at Cilanw, and on Felin-isa Hill. In a roadside exposure near Llanboidy Bridge, however, graptolites are tolerably plentiful: *Didymograptus bifidus*, Hall, and *D. Murchisoni*, var. *geminus*, His., occur.

Search for fossils in the *D.-bifidus* Beds west of the Gronw has not been attended with much success: only a few fragmentary specimens of graptolites have been found. A crushed specimen of *D. bifidus* was obtained from shales in the railway-cutting, a quarter of a mile north of Login; another of the same description in the dingle east of Maencoch-yr-wyn, and a few more at Llanglydwen, a short distance from the base of the *Didymograptus-Murchisoni* Beds.

In the absence of fossils, the general character of the beds renders them fairly easy to recognize; besides, the ash-bands which are associated with them supply useful landmarks.

The second outcrop is isolated from the first by a belt of newer beds faulted down or folded in. It extends from a point a short distance east of Clyngwynne House to another point a short distance south-west of Cwrtau-bach. *Didymograptus bifidus* was collected from the following localities:—A well in Clyngwynne field; the road-section at Cross-in; roadside exposures near the Parsonage; Parsonage Quarry; Common Quarry; Wern-oleu-fawr; roadside north of Post-gwyn; and Cwrtau-bach.

A diabase-dyke cuts obliquely through the outcrop near Parsonage Farm, and is quarried for road-metal in the Parsonage Quarry. The beds roll about a good deal near Cwrtau-bach, owing no doubt to much faulting in the immediate neighbourhood. On the north the beds pass up normally, except from Wern-y-berni westward, where the succession seems to be broken by a fault—probably a thrust.

(3) Conclusions.—The occurrence of *Didymograptus Murchisoni* var. *geminus* in certain sections suggests the propriety of separating those beds from the *D.-bifidus*, and including them in the *D.-Murchisoni* Series; but certain considerations make that arrangement inconvenient and illogical, so far as the two faunas are represented in this district.

In the first place, *D. Murchisoni* var. *geminus* appears rather low down in the series, associated with a fair number of graptolites—extensiform and others—of true *D.-bifidus* age; in the second place, much higher beds have yielded series of fossils of true *D.-bifidus* facies; and in the third place, there is in this district a natural well-defined line of demarcation between the *D.-Murchisoni* Beds and those of *D.-bifidus* age—a line characterized by lithological and faunal conditions, and easily traced wherever the two series occur in normal succession.

(c) Llanvirn Group: *Didymograptus-Murchisoni* Beds.

(1) South of the Anticline.—In the absence of a single exposure, it is doubtful whether these beds occur at all on the south of the anticline. A few fragments of striped flags, containing isolated stipes of 'forked' graptolites, have been found in the soil, near a small quarry in *Asaphus-tyrannus* Limestones north of Lower Court. The general aspect of the specimens suggests *Didymograptus-Murchisoni* Beds.

Black mudstones containing crowds of 'forked' graptolites, associated with great numbers of *Siphonotreta micula* and a few specimens of *Orthoceras*, have been dug out of a well at Croft Lodge. These beds, with their fossil contents, bear a striking resemblance to black mudstones underlying and passing up into *Asaphus*-Limestones near Lan Mills.

The graptolite-mudstones at Croft Lodge underlie *Didymograptus-bifidus* Beds, and do not come to the surface anywhere in the neighbourhood—a fact which adds force to the view that there is an extensive overfolding here.

(2) North of the Anticline.—The *Didymograptus-Murchisoni* Beds are, however, well developed on the north of the anticline, and form a definite and useful stratigraphical landmark.

The series is made up of three members. The lower member consists of black mudstones which, on weathering, become fawn and cream-coloured, easily distinguishable from the underlying *D.-bifidus* Beds. Incipient striping is observable in the very lowest beds, but this characteristic becomes more pronounced towards the top. The beds are crowded with 'forked' graptolites; but with one solitary exception, no other kind of fossil has been found. The black mudstones in Frowen Dingle have yielded one trilobite-tail which probably belonged to an *Ogygia*. The graptolites include *Didymograptus Murchisoni*, Beck, and *D. Murchisoni* var. *geminus*, His.

The middle member is made up of several beds of blue ash, with interbeddings of ashy shales. Neither ashes nor shales have yielded any fossils.

The upper member consists of striped flags, and thickly-bedded arenaceous mudstones, rather highly cleaved. The fossils, and even the bedding, are sometimes obscured by the cleavage; but the beds are, as a rule, readily recognized from their characteristic texture and striping. Under normal conditions fossils are abundant and typical, and include:—*Didymograptus Murchisoni*, Beck; *D. Murchisoni* var. *geminus*, His.; *D.* cf. *indentus*, Hall; *D. foliaceus*, Murch.; *D.* cf. *dentatus*, Brongn.; *Climacograptus cœlatus*, Lapw.; *Siphonotreta micula*, M'Coy: *Lingula* cf. *attenuata*, Sow., etc.

These beds enter the district at Melin-ricket, where they are well exposed near the mill. The upper and middle members are clearly shown in a quarry, where the beds are vertical. The lower division is seen in a garden adjoining the quarry on the south, where they pass down rather abruptly into *Didymograptus-bifidus* Beds with a fair abundance of typical fossils.

They are again seen in the wood on the west of the valley, and in a quarry on the brow of the hill above. Only the upper division, however, is exposed here. From this quarry their débris is traceable to a point a little south-west of Bwlch, where they are cut off by a fault and thrown southwards, again appearing in the dingle north-east of Cefn-crwth. Passing under the house at that place they appear in a quarry in the rickyard, where typical fossils are abundant. They run west along the ridge, and are again well seen in the Dewi-fawr Valley, a third of a mile south of Mydrim. On the eastern side there are several good sections, but presumably only the upper division is again seen. In Pant-yr-hendref Quarry opposite, these beds are merely uncovered by quarrying operations in higher beds. Westward from here again they run along the crest of the ridge, cropping out on the Salem Road south of Oernant and make for the Gynin Valley, but before reaching it they are cut out by a fault which brings *D.-bifidus* Beds against *Dicranograptus*-Beds. On the hill south of Castell-gorfod they are again seen in quarries and otherwise, but here and along the ridge westward

there is evidence of their being inverted. This was probably brought about by an overfold from the north developed into a thrust. Here begin the complicated overfolding and faulting that have so much disturbed the country farther west. This outcrop is cut off by a low-hading fault—the thrust, in the dingle south of Penlan; but it comes to the surface again about a furlong farther west, abundant striped fossiliferous débris in the soil indicating its whereabouts.

The beds are exposed on the main road north-west of Penlan, and a quarry has been opened in them on the side of the hill south of Caerlleon. Higher beds are exposed on the top of the hill, but on the northern slope a thrust has brought up the *Didymograptus-Murchisoni* Beds and has carried them forward so as to overlap some of the higher beds. Both outcrops are cut off on the slope overlooking Melin Nant-yr-eglwys, *Didymograptus-bifidus* Beds being exposed at several points on the slope below.

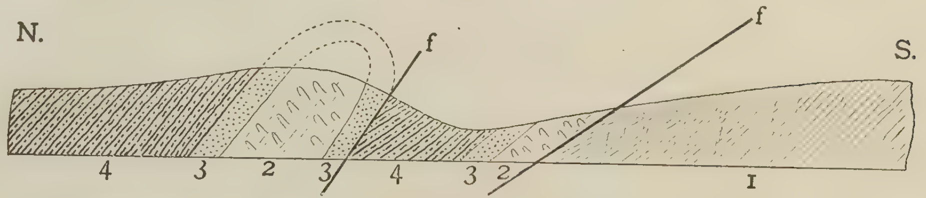
At Nant-yr-eglwys there are at least four distinct outcrops. One passes through the yard, and is flanked on both sides by higher beds—a fact which suggests a small anticlinal fold, but a much broken one. The other outcrops are formed of dismembered portions of the main outcrop, cut up by buckling and faulting.

Down in the valley, south-east of Nant-yr-eglwys, is a small opening in the upper division of the beds, with some ash-débris below. From here the outcrop sweeps in a curve along the brow of the hill above Llethr-madyn and Fronboeth, to a point about a furlong north of Clynpebyll, where it is cut off by a fault. There is a short break in the outcrop due south of Nant-yr-eglwys, where the beds are shifted northwards for a distance of about 200 yards, and are seen in the lane.

From the point where the *D.-Murchisoni* Beds disappear near Clynpebyll to another point near Hafod Llanboidy, higher beds, including *Dicranograptus*-Shales and *Asaphus-tyrannus* Ash, are faulted against *Didymograptus-bifidus* Mudstones; but at the latter place *D.-Murchisoni* Beds come to the surface once more, and are traceable as far as a point a short distance south of Maesgwyn-isaf, where they enter a fault—not to appear again between this spot and the Tave.

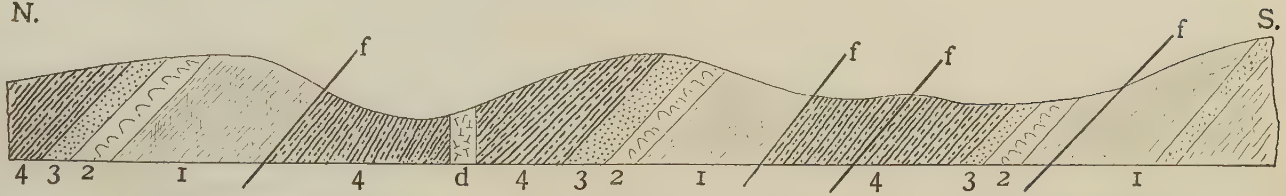
On the north, another outcrop comes out of a fault at Pengaer-fach, a quarter of a mile west of Llanboidy, where the *D.-Murchisoni* Beds form a peculiar and prominent feature in a field near the quarries in the ash. This outcrop strikes west, passing under Maesgwynne House and appearing in the southernmost of the Pensarn Quarries. The beds are again seen crossing the road to the west, and in the Frowen Wood, where there is a complete section across them. They are also seen in the dingle, and are traceable up the hill on the west. They sweep northward with the contour of the hill on the western slope, producing an unmistakable and continuous line of débris. But west of Frowen they are cut off by an east-and-west fault, which displaces the outcrop for about 400 yards, and renders the structure somewhat obscure.

Fig. 4.—*Section from north to south, near Nant-yr-eglwys, on the scale of 6 inches to the mile. (Marked on the map, Pl. XLVI, as 'Section VI.')*



1 = *Didymograptus-bifidus* Beds.
2 = *Didymograptus-Murchisoni* Beds.
3 = *Asaphus-tyrannus* Ash.
4 = *Dicranograptus*-Beds.
f f = Faults.

Fig. 5.—*Section from north to south, near Llanboidy, on the scale of 2 inches to the mile. (Marked on the map, Pl. XLVI, as 'Section VII.')*



1 = *Didymograptus-bifidus* Beds.
2 = *Didymograptus-Murchisoni* Beds.
3 = *Asaphus-tyrannus* Ash.
4 = *Dicranograptus*-Beds.
d = Diabase-dyke.
f f = Faults.

About 100 yards south of Cefn-pant Chapel there is another short outcrop let out by an east-and-west fault, seen in section in Canerw Quarry. (The *Didymograptus-Murchisoni* Beds are not seen at the quarry.) This outcrop strikes into *D.-bifidus* Mudstone at Trehir-isaf, and no more of it is seen farther west.

There is yet another extensive, but much broken outcrop, let out by the complicated faulting of Nant-yr-eglwys. The easternmost exposure in this outcrop is seen in a field, at the end of the lane south of Maencoch. The beds are also exposed in the lane itself, and there is much débris in the soil for some distance south, but not in line with the strike of the beds in the lane; besides, the lane-beds strike into *Dicranograptus*-Beds in the immediate neighbourhood. North-westward these beds are traceable to a point some little distance south of Llain (Lleinau), where the lower division is seen in a road-exposure, and the whole in the bed of the river to the west. A small quarry has been opened in them south of Trebleiddiau, and they are seen crossing the road close by. There is no other exposure, but débris is traceable a quarter of a mile farther along the same strike, which ends abruptly in *D.-bifidus* Beds, the *D.-Murchisoni* Beds being thrown about 200 yards to the north, and cropping out in the lower part of Wern-berni farmyard. From here they strike due westwards, and are seen again at Cwrtau-bach, in the lane near the well; but here the beds are much cleaved, and are disturbed by a fault which causes a slight displacement. A quarter of a mile to the west they are faulted down, and pass under higher beds.

The ground round Llwynllwyd is very complicated, owing to much faulting. Although lower and higher beds are abundantly exposed, there is no well-defined outcrop of *D.-Murchisoni* Beds. Slight traces of them have been detected in several localities, but there is not a single exposure. A little farther north, however, the whole series is again seen in the dingle north of Tycoed, and is traceable westward to Abertigan, being faulted on the south against *Dicranograptus*-Shales. The beds are well seen in the watercourses south of Abertigan and on the road at Tigan, immediately north of the ford near Llanglydwen Station.

On the west of the river there is a complete section across them near the bridge, where the three divisions are well represented. The ash has been quarried here, just where the limestone-mark is on the Survey-map. There are calcareous lumps in the ash, and some attempts have been made to burn them. The kiln built for that purpose was standing until very recently. It cannot be made out, however, on what grounds it was thought that there are limestone-rocks here in contact with a cupriferous vein. There are some old workings a little distance to the south, but there are no limestone-rocks, neither was any copper found.

The *Didymograptus-Murchisoni* Beds run westward through the 'Castell' and come out on the road near the mill, and at the junction of the roads south of Pengawsai, where the ash is extensively quarried for road-metal, and the striped beds are exposed in the roadway.

(3) Conclusions.—These beds seem to have been deposited under conditions exceedingly suitable for the preservation of 'forked' graptolites. Many of the bedding-planes are covered with a perfect mat of these fossils, while biserial and other types of twin graptolites are comparatively rare.

The lighter stripe is due to a thin layer of more ashy material, and the ash-band is presumably a 'light' stripe of larger dimensions, owing to greater activity in the production of the material.

(*d*) Llandeilo Group: *Asaphus-tyrannus* Beds.

(1) South of the Anticline.—The beds occurring on the south of the anticline are of the typical description, and consist of black limestones and calcareous black shales. The fossils are of the usual type, and include:—

Asaphus tyrannus, Murch.
Ogygia Buchii, Brongn.
Homalonotus.
Trinucleus Lloydii, Murch.
Trinucleus fimbriatus, Murch.
Trinucleus favus, Salt.
Calymene brevicapitata, Portl.
Calymene cambrensis, Salt.
Acidaspis cf. *Jamesi*, Salt.
Beyrichia complicata, Salt.
Favosites sp.
Orthis striatula, Emm.
Orthis vespertilio, Sow.
Orthis calligramma, Dalm.
Orthis testudinaria, Dalm.
Orthis elegantula, Dalm.
Orthis biforata, Schloth.
Orthis triangularis, Sow.
Strophomena corrugatella, Dav.
Strophomena compressa var. *llandeiloensis*, Salt.
Siphonotreta micula, M'Coy.
Lingula granulata, Phill.
Lingula cf. *attenuata*, Sow.
Leptæna cf. *sericea*; etc.

There are only three localities where these beds come to the surface, and all of them lie on the line of an extensive east-and-west fault, which accounts for the paucity of exposures.

In a quarry north of Lower Court the beds are well seen, and are very fossiliferous, having yielded specimens of all the species mentioned in the foregoing list. The more arenaceous beds exhibit the typical striping of the *Didymograptus-Murchisoni* Beds. (These beds are not exposed here, but are believed to be present immediately north of the quarry.) The beds here dip northward at about 45°, and appear to pass under the *D.-Murchisoni* and the *D.-bifidus* Beds of Danrallt; a fact which leads to the conclusion that the strata are here upside down, by reason of the overfolding already referred to.

North of Pant-dwfn there is another quarry in these deposits; but the dip is here a little west of south, and the beds are in their normal position. This is, seemingly, the only fossil-locality known to earlier writers.

Immediately west of this quarry the beds are cut off by the fault which brings the black *Dicranograptus*-Shales against *Didymograptus-bifidus* Beds near St. Clear's Bridge. The effects of this fault are seen in several places between St. Clear's and Clôg-y-frân, where the *Asaphus*-Beds are again well exposed, in several quarries which have, in years gone by, supplied much stone for lime-burning.

This is the limestone-locality mentioned by George Owen more than three centuries ago.

The beds are well developed here, some of them being upwards of 6 feet thick. This outcrop is that of a large lenticle, faulted against other beds all round. In the old quarry near the house the beds have been worked out into the faults, which brought them against *Didymograptus-bifidus* Beds on the north and against Bala rocks on the east and south. Some of the beds are highly fossiliferous, bands of limestone being entirely composed of *Orthis*. *Asaphus tyrannus* occurs here, but perhaps not quite so abundantly as at Lower Court. *Trinucleus* occurs in crowds, in the tump of crushed limestone by the side of the lane.

Farther west the nearest exposure is at Waundwrgi, 2 miles west of Whitland, in Messrs. Marr & Roberts's ground.

(2) North of the Anticline.—Very different from rocks of the same age on the south, the *Asaphus-tyrannus* Beds on the north are singularly devoid of calcareous matter. They here consist of ash and ashy shales, compact in places, and generally abounding in fossils. They lie immediately upon *Didymograptus-Murchisoni* Beds, and the conditions under which they were deposited were so uncongenial to graptolite-life that *D. Murchisoni*, so abundant in the beds below, disappeared abruptly, not to reappear again. Not a single specimen has been discovered, either in the ashes or in the beds above them. Trilobites, however, are fairly abundant in the ash-bands and in the shales, and are associated—in the higher beds—with graptolites of biserial type.

As these beds invariably follow *Didymograptus-Murchisoni* striped flags, their outcrops will not be followed here in detail. Only such exposures will be dealt with as afford the most convenient opportunity for the study of the beds.

At Pant-yr-hendref Quarry, a short distance south of Mydrim, the *Asaphus-tyrannus* Ash is quarried for road-metal and building purposes; and this is the place where it is best developed in the whole district. In the fresh condition, some of the layers are fine-grained, even flinty, and dark blue in colour. They weather into various shades of brown, cream-colour, and even white, but they generally retain their hardness. The upper beds are somewhat sandy and flaggy, yielding a few graptolites. The following fossils occur here:—

Diplograptus foliaceus, Murch.
Climacograptus sp.
Asaphus tyrannus, Murch.
Ogygia Buchii, Brongn.
Acidaspis sp.
Trinucleus Lloydii, Murch.
Trinucleus favus, Salt.
Orthis vespertilio, Sow.
Lingula granulata, Phill.
Lingula sp.
Orthoceras; etc.

Eastwards the beds are not seen in Melin-ricket Quarry, but they form a tump in the field 40 yards to the north. They are exposed in the Llysonnen Quarry opposite, and contain fair numbers

of trilobites. They are also seen in Pantglâs Quarry, in the Dewi-fawr Valley. As they are followed westward they become modified in character, being still ashy, but much less compact, so that at Llanboidy they have become soft, easily-dressed stone. They have been quarried for building at Hafod and Pengaerfach, and are well exposed in an old quarry in a garden at Maesgwynne. At Pensarn, west of that locality, they have been extensively quarried, supplying building-stone for the country round. They are very fossiliferous here, yielding *Asaphus tyrannus*, Murch., *Ogygia Buchii*, Brongn., *Homalonotus*, *Trinucleus*, and graptolites, etc. They have also been quarried in the wood south of Frowen. At Llanboidy and westward they are immediately overlain by black shales crowded with *Diplograptus*, associated with trilobites—chiefly *Trinucleus Lloydii*, Murch., *Tr. favus*, Salt., *Ogygia Buchii*, Brongn., also a few specimens of *Orthis*, and large numbers of *Lingula granulata*, Phill.

In the quarry north of Canerw, already referred to, these beds have been brought up against higher beds by a thrust from the north. In a quarry north of Trehir (at Cefn-trehir) the ash is quarried for road-metal; but its relation to other beds here is far from clear, owing to some obscure faulting in the immediate vicinity.

Along the northernmost outcrop there are no quarries, and the presence of the beds, as well as their character, has to be inferred from road- and ditch-exposures. From what evidence there is, it is premised that the ash thins out and the shales become less ashy and more argillaceous as they pass northward. The Llanglydwen-Lane section, north of the bridge, proves this, as no hard beds occur there at all, though the section is otherwise complete and typical.

(*e*) Llandeilo Group: *Dicranograptus*-Beds.

These rocks occupy a considerable portion of the area, both north and south of the anticline. Exposures are numerous, and usually the beds are highly fossiliferous. A very noticeable feature in the character of the beds is, that they contain much iron-pyrites. This is so abundant in some localities, that springs issuing from the black shales assume the appearance and character of those found in the vicinity of coal- and iron-mines.

(1) South of the Anticline.—The passage upwards from the *Asaphus-tyrannus* Beds is nowhere to be observed on the south of the anticline, but the *Dicranograptus*-Beds themselves are seen passing up in several localities.

The beds are well exposed in the neighbourhood of St. Clear's, and a good section is seen immediately north of the bridge across the Tave, and in close proximity to the east-and-west fault mentioned above (p. 614). The shales are here intensely black and somewhat

ashy, with a fair abundance of fossils. Here, presumably, Prof. Lapworth collected graptolites which he identified as follows:—

Dicranograptus formosus, Hopk.
Dicellograptus sextans, Hall.
Diplograptus foliaceus, Murch.
Climacograptus cœlatus, Lapw.
Climacograptus perexcavatus, Lapw.

The following additional fossils have been obtained from a well close by:—

Dendrograptus sp.
Climacograptus tubuliferus, Lapw.
Corynoides curtus, Lapw.
Orthis argentea, His.

East of the Gynin, the beds are seen near the old lime-kiln at Llandeilo-aber-cowyn, where *Orthis argentea*, His., occurs. The beds here are easily recognizable, although graptolites are very rare. Their passage upwards is also seen in a very good and continuous section.

Black shales of the same description have been dug from a well at Foxhole, are seen in a ditch east of Division Park, and from abundant débris are known to be present in the small hill or ridge north of that fault, but are here evidently faulted against higher beds.

The dips north and south of the Cywyn, near where it falls into the Tave, indicate an anticlinal fold of some extent. The fold itself, however, has been worn away, and its place is now occupied by the Cywyn Valley. Conditions pointing to the same fact are also seen on the west of the Tave.

Black shales are exposed in a small pit in the Corporation ground south of Morfa-bach. Their occurrence here is accounted for by the Cywyn anticline, but there is some faulting in the vicinity.

Immediately south of Woolston Farm are several exposures of black shales, some of which can be traced to the St. Clear's-Bridge Fault. The beds also occur in the high bank of the Tave, near Llysywig, but are not very fossiliferous. There are moreover several other small exposures in the neighbourhood, which are useful to point out the path of the fault.

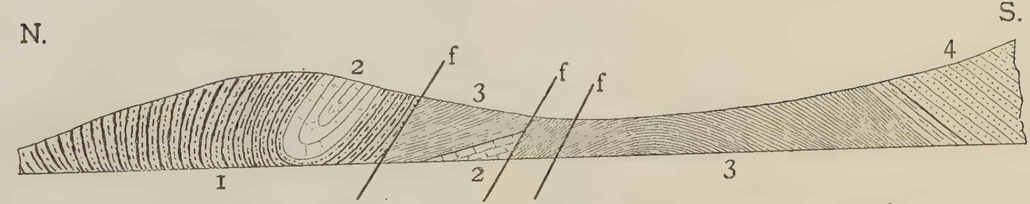
The beds are well and typically exposed, both in quarry- and road-sections, south of Mylet. Here they are abundantly fossiliferous, and are seen passing up into arenaceous deposits—rotten limestone—full of fossils. The black shales have yielded the following fossils:—

Dicranograptus rectus, Hopk.
Dicellograptus Morrisii, Hopk.
Climacograptus tubuliferus, Lapw.
Climacograptus minimus, Elles.
Callograptus (two species);
etc.

Some other good exposures are seen near Moelden. Here the beds show signs of shearing and other disturbances. The black shales pass up somewhat abruptly into rotten limestone, most of which seems to have been pinched out, and a little to the east disappears altogether.

From this point to near Llanddowror there is a small synclinal fold enclosing rotten Bala Limestone. Parallel to this, on the

Fig. 6.—*Section east of Llanddowror, on the scale of 6 inches to the mile.*
(Marked on the map, Pl. XLVI, as 'Section I.')

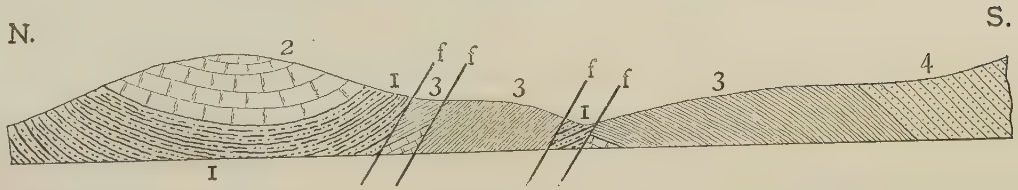


1 = *Dicranograptus*-Beds.
2 = Bala Limestone.

3 = Redhill and Slade Beds.
4 = Old Red Sandstone.

f f = Faults.

Fig. 7.—*Section west of Llanddowror, on the scale of 6 inches to the mile.*
(Marked on the map, Pl. XLVI, as 'Section II.')



1 = *Dicranograptus*-Beds.
2 = Bala Limestone.

3 = Redhill and Slade Beds.
4 = Old Red Sandstone.

f f = Faults.

south of it, is an east-and-west fault, which brings the *Dicranograptus*-Beds against Upper Bala rocks. The structure is made tolerably clear by several useful exposures at and near Maeslan and along the Penygraig lane, where the fold and fault are seen in section.

The black shales are much exposed at Llanddowror, particularly near the Rectory,[1] along the old road, and up the Maeslan lane. The character of the rock is fairly constant, and fossils are moderately plentiful. The section at the Rectory has yielded :—

Diplograptus foliaceus, Murch.	*Dicranograptus Clingani.*
Climacograptus tubuliferus, Lapw.	*Corynoides curtus*, Lapw.
Climacograptus perexcavatus, Lapw.	*Holopella* sp.
Glossograptus sp.	*Orthoceras.*
Dicellograptus sp.	*Discina*; etc.

From Llanddowror Bridge, some distance up towards Pentrehowel, there is a very instructive exposure. Here can be seen the gradual upward passage of the black shales to the Bala-Limestone stage above. The shales become increasingly arenaceous: thin bands with crinoid-ossicles, etc. become frequent; *Orthis* and other brachiopods, as well as cephalopods, make their appearance. The lower limestone-bands have lost their lime, and have assumed the character of a light greyish-buff sandstone; but on the brow of the hill the rock is still strongly calcareous.

The lane leading to Faynor discloses a small section in the black shales coming out under the Bala Limestone of Llanddowror Quarry. They are here faulted against Upper Bala Beds. (See fig. 7, p. 628.)

Another strip of *Dicranograptus*-Shales extends from near Talfan Lodge to Cwmcaedu, and is faulted against Upper Bala both on the north and on the south. (Near Talfan are seen traces of mining operations in these beds—presumably another endeavour to find coal.)

In the dingle south-west of Faynor, the black shales are let out by one of the numerous faults which traverse this locality, but the outcrop is of very limited extent.

(2) North of the Anticline.—From Pant-yr-hendref Quarry to a point 100 yards north of Mydrim, there is almost a continuous road-section across the *Dicranograptus*-Beds. For convenience in the field, these beds are divided into three subgroups, according to their lithological characters :—

α—Black shales, weathering into various shades of buff and yellow;
β—Black shales, with lenticular limestone-bands;
γ—Black slaty shales which crumble on weathering, but do not bleach.

This subdivision will also, to some extent, hold good palæontologically, inasmuch as the assemblage of fossils varies concurrently with the lithological changes. In the buff-yellow beds graptolites,

[1] A short distance east of the Rectory a level has been driven into these shales in search of coal.

trilobites, and brachiopods occur in fair numbers. The calcareous beds contain a few trilobites at the base, but graptolites are very abundant throughout, even in the compact limestone. The slaty black shales contain graptolites in profusion, and little else.

(a) From Melin-ricket to Penlan there is only one definite area occupied by the buff-yellow beds. The upward passage from the *Asaphus-tyrannus* Beds can be well seen at Llysonnen Quarry, in the road-section north of Peny-bigwrn, Lan Quarries, Pant-yr-hendref Quarry, and the road-section south of Oernant-uchaf. Fossils occur at all these localities, the following being the most abundant :—

Diplograptus foliaceus, Murch.
Climacograptus sp.
Dicellograptus sextans, Hall.
Dicranograptus ramosus, Hall.
Dicranograptus cf. *rectus*, Hopk.
Ogygia Buchii, Brongn.
Trinucleus favus, Salt.
Orthis calligramma, Dalm.
Orthis testudinaria, Dalm.
Orthis elegantula, Dalm.
Lingula cf. *granulata*, Phill.
Lingula attenuata, Sow.
Siphonotreta micula, M'Coy.

South-east of Castell-gorfod these beds are faulted against *Didymograptus-bifidus* Beds on the south. Near Castell Quarry, however, the *Asaphus*-Ash and the *Didymograptus-Murchisoni* Flags are brought against them by the same fault; but a little farther west they are again thrown against *D.-bifidus* Beds.

Near Penlan, the main area is split into two by a thrust from the north (already referred to), and in the Fenni Valley, near Melin-nant-yr-eglwys, the beds are almost entirely cut out by a number of faults. At Nant-yr-eglwys they are very much broken up by the faults, which have similarly affected other beds, already described.

From Blaensarngoch westward, as far as the neighbourhood of Llanboidy, the *Dicranograptus*-Beds occupy a well-defined area, and are faulted against *Didymograptus-bifidus* Beds both on the north and on the south. They are well seen in the low ground west of Clyngwynne—around Waunfawr and Waunfach. On the road near Ddol, and in Parsonage Farmyard, they are full of fossils of the usual type; they are also well exposed and fossiliferous at Wern-oleu-fach and Wern-oleu-fawr.

In the immediate vicinity of Llanboidy they have been cut up by faulting, and at Pengaerfach the outcrop is split into two by a ridge of older beds. One outcrop follows that of the *Asaphus-tyrannus* Beds in the direction of Maesgwyn-isaf, where, like the older beds, they are cut off by a fault. The other outcrop occupies the low ground between Wern-oleu-fawr and Frowen, stretching from Pensarn Quarry on the south to Canerw Quarry on the north. West of Frowen the beds run out on the ridge, as the older beds—*Didymograptus-Murchisoni* Flags and *Asaphus-tyrannus* Ash—were said to do.

Following the northern outcrop of the *Asaphus-tyrannus* Ash is another belt of buff-yellow *Dicranograptus*-Beds, traceable from Nant-yr-eglwys Mill past Maencoch, Llain, Trebleiddiau, and

Dyffryn. At Wern-y-berni they are thrown northwards by some obscure faulting, and are well seen at Sarnau, Cwrtau-mawr, and Cwrtau-bach. The cut-up character of the ground west of Cwrtau-bach and round Llwyn-llwyd and Lan affords abundant exposures, but it is often very difficult to trace the relation between the various beds. The road near Tycoed and Waungron affords a continuous exposure, but fossils are obscured by cleavage. South of Abertigan the beds run out in a manner similar to that observed west of Frowen. On the north the beds are faulted against *Didymograptus-Murchisoni* Flags.

Another belt of these beds follows the Llanglydwen-Abertigan outcrop of *Asaphus*-Beds, and, like them, is cut off by a fault near Fron-isaf.

(β) Calcareous bands.—It is suspected that there is a calcareous development of the buff-yellow weathering mudstones at more than one horizon; but it is quite clear that the most persistent of them is very local. Whether this is due to conditions of sedimentation, or to subsequent weathering and decalcification, has not been made out.

At the village of Mydrim there is a considerable thickness of calcareous beds, some lenticular bands being fairly-compact blue-black limestone. A good section of the beds is seen under the graveyard, and fossils are abundant: some bands are crowded with graptolites of types hitherto unknown elsewhere in South Wales. The following have been identified:—

Leptograptus validus, Lapw.
Leptograptus grandis, Lapw.
Leptograptus latus, Elles & Wood.
Dicellograptus cf. *sextans*, Hall.
Dicranograptus brevicaulis, Elles & Wood.
Dicranograptus cf. *Nicholsoni*, Hopk.
Dicranograptus rectus, Hopk.
Dicranograptus, sp. (new).
Diplograptus cf. *foliaceus*, Murch.
Didymograptus superstes, Lapw.
Climacograptus sp.
Glossograptus (?) Hincksii, Hopk.
Dictyograptus sp.
Trinucleus favus, Salt.
Trinucleus sp.
Orthis testudinaria, Dalm.; etc.

Eastward, these beds are only traceable for a short distance, but westward they are more persistent.

A well has recently been sunk at Oernant-uchaf, cutting through most of these beds, and the material brought up has yielded fossils of the above description and, in addition, two or three poor specimens of *Nemagraptus gracilis*, Hall.

At Castell-gorfod the beds have been quarried for lime-burning; but it does not appear that the experiment was attended with much success.

The beds occur at Penlan, but the limestone is very thin. It does not come to the surface at all between here and Llain, where an occasional slab occurs among the black shales. The same beds are seen in a deep ditch immediately west of Trebleiddiau; but they are exceedingly rotten, yielding only an occasional slab of compact

limestone. Fossils also occur, but it is very difficult to secure a good specimen, owing to the extreme friability of the rock.

At Dyffryn, a quarter of a mile to the north, however, the beds are much stronger, and have yielded limestone for lime-burning, a portion of the old kiln being still in evidence. The section exposed in this old quarry is very instructive, as showing the true relation of the limestones to the beds above and below. The several alternations of calcareous bands with buff-yellow mudstones and shales prove conclusively that the limestones belong to the beds below, rather than to the slaty black beds above.

West of this section the limestones are traceable up the dingle towards Sarnau, but they completely disappear before that point is reached.

(γ) The black slaty beds.—These form a belt of varying width along the northern margin of the ground. They are highly cleaved and intensely black, except that in some localities they contain a good deal of what appear at first sight to be mica-flakes. On closer examination, however, the regular triangular form of these tiny bodies points to their organic origin, and it is suggested that they are graptolite 'embryos,' or what afterwards became siculæ.

Although the beds are, as a rule, highly fossiliferous, they have yielded little besides graptolites, and these, owing to cleavage, very much distorted. Iron-pyrites is also very abundant. There are abundant exposures all along their outcrop, and quarries have been opened in them at frequent intervals—occasionally for building-material, but much oftener for drain-rubble.

They enter the district at Rhyd-aber-wern near Melin-ricket, and are frequently seen up the dingle in the direction of Bwlch, Sarnau, Penrheol, and Mydrim, at all of which places they are exposed in quarries and otherwise. They are well seen on Llangarthgynin Hill, near Trip Bridge, and along the road leading to Caerlleon Farm. They are affected by much faulting north of Penlan, and their junction with the brown-grey mudstones above has been thrown northwards from near Trip Bridge to a point some distance north of Melin-dol-goediog.

They are much in evidence again at Melin-nant-yr-eglwys, where they are considerably cut up by faults. Fossils are very abundant, but distorted, in Melin-nant-yr-eglwys Quarry. The following occur:—

Dicranograptus rectus, Hopk.
Dicranograptus Nicholsoni (?) Hopk.
Diplograptus foliaceus, Murch.
Climacograptus cf. *tubuliferus*, Lapw.
Climacograptus sp.
Glossograptus sp.

The black beds frequently come to the surface on both sides of the Fenni, as far as Llechglawdd, near which place they are abundantly exposed, but pass up into higher beds—the brown-grey mudstones—in the immediate neighbourhood.

At Cwm-felin-mynach they are so much cleaved that both bedding and fossils are obliterated. From Cwm-felin they are traceable up

the dingle south of Waun-rhyddod and Bronysgawen, past Sarnau, to Glanrhyd, south of Eglwys-Fair-a-Churig, where they have yielded fossils of the Melin-nant-yr-eglwys type.

South of Fron-isaf the outcrop is shifted for some distance northward by a fault. From here the black beds follow the lower beds normally, and are typically exposed near Sylvania Factory, where they have yielded *Orthis argentea*, His.

A short distance south of Llanglydwen Station a 'lenticle' of these beds has been faulted in among *Didymograptus-bifidus* Beds. They can be well seen near the signal-post, where they have yielded a few distorted graptolites and *Orthis argentea*, His. They are also very pyritous here, as elsewhere.

(3) Conclusions.—The occurrence of *Orthis argentea* in these shales tends to show that they cannot be of Llandeilo age.

The late Thomas Roberts reported the occurrence of *O. argentea* at Dyffryn-pwdryn north of Llanboidy and elsewhere, where the succession is practically the same as at Mydrim. Mr. Roberts presumably found his specimens in the black slaty beds, which are the equivalents of the beds at Fron-isaf and Llanglydwen.

The graptolitic fauna of a considerable portion of these beds is, in the opinion of Miss Elles, more characteristic of Llandeilo than of Bala-Caradoc age; but further search for fossils, and a closer examination of both beds and fossil-forms, will probably bring forth evidence showing that the upper portion is of Bala-Caradoc age. Until that is done the matter must remain unsettled.

(*f*) Bala-Caradoc Rocks.

Bala-Caradoc rocks of Pembrokeshire type are well developed in the district, and are readily divisible into the four groups enumerated by Dr. J. E. Marr & the late Thomas Roberts in their paper on the Haverfordwest district,[1] namely :—

(α) Robeston-Wathen Limestone.—Limestones and calcareous shales.
(β) Sholeshook Beds.—Arenaceous limestones.
(γ) Redhill Beds.—Blue-grey mudstones and shales, with some thin sandstone-bands.
(δ) Slade Beds.—Blue-grey mudstones and shales, with limestone-bands.

(1) South of the Anticline.

(α) Robeston-Wathen Beds.—These beds are typically exposed immediately north of Llandeilo-aber-cowyn, where the *Dicranograptus*-Shales are seen passing up. Some of the limestone-beds are very compact and break sharply under the hammer, but weather into dust. An unusual feature observed here is the occurrence of lines of pebbles in some of the beds. The compact limestone is fairly fossiliferous, but better specimens can be collected from the calcareous shale-partings. (For fossils see the appended list, pp. 634–35.)

[1] Quart. Journ. Geol. Soc. vol. xli (1885) p. 476.

List of Bala-Limestone Fossils. (Robeston-Wathen and Sholeshook Limestones.)

Names of Species.	α.		& β.			α? & β.	β.		
	Foxhole.	Bronhaul.	Llandeilo-aber-Cowyn.	Clôg-y-frân Farmyard.	Moelden.	Llanddowror.	Clôg-y-frân Wood.	Trefanty.	Faynor.
Nidulites favus, Salt.	...	...	...	...	...	×	×	×	
Callograptus sp.	...	...	...	...	...	×			
Heliolites interstinctus, Wahl.	...	...	...	...	×	×	×	×	×
Heliolites megastoma, M'Coy	...	...	...	...	...	×	×	...	×
Heliolites inordinatus, Lonsd.	×	×	×	×					
Favosites fibrosa, Goldf.	×	...	...	...	...	×	×	×	×
Favosites gothlandica, Fougt.	...	...	×	...	...	×			
Monticulipora lens, M'Coy	...	...	...	...	...	×	×	×	
Monticulipora favulosa, Phill.	...	...	?	...	...	×			
Halysites catenularia, Linn.	×	×	×	×	...	×			
Sphæronites stelluliferus, Eichw.	...	...	...	...	...	×	×		
Syringophyllum organum, Linn.	×	...	×	...	...	×			
Petraia rugosa, Phill.	×	×	×	×	...	×	...	×	×
Petraia equisulcata, M'Coy	×	...	...	...	...	×			
Petraia elongata, Phill.	×								
Cyathophyllum articulatum, Wahl.	×	...	×						
Omphyma turbinata, Fougt.	×	...	...	×	...	×			
Echinosphærites balticus, Eichw.	...	...	...	...	...	×			
Glyptocrinus basalis, M'Coy	...	...	...	×	...	×	...	×	
Serpulites dispar, Salt.	...	...	...	...	...	×			
Cornulites serpularius, Schloth.	...	...	...	...	...	?			
Tentaculites anglicus, Salt.	...	...	...	...	...	?			
Fenestella subantiqua, D'Orb.	...	...	...	...	...	×	...	×	
Glauconome disticha, Goldf.	...	...	...	...	...	×	×	...	×
Ptilodictya dichotoma, Portl.	...	...	...	...	...	×			
Ptilodictya costellata, M'Coy	...	...	...	...	...	×			
Beyrichia sp.	...	...	...	...	...	×	...	×	
Agnostus trinodus, Salt.	...	×	...	...	...	×			
Illænus Bowmanni, Salt.	×	...	×	×	×	×	×	×	×
Calymene Blumenbachii, Brongn.	...	...	...	...	...	×	×	×	
Calymene brevicapitata, Portl.	...	...	...	...	...	×			
Calymene duplicata, Murch.	...	...	...	...	...	×	...	×	
Encrinurus punctatus, Brünn	...	...	...	...	×	×	×	×	
Encrinurus sexcostatus, Salt.	×	...	×	...	...	×	×	...	×
Staurocephalus globiceps, Portl.	...	...	...	...	...	×			
Cybele verrucosa, Dalm.	...	...	...	...	...	×	×	×	×
Cybele rugosa, Portl.	...	...	...	...	...	×	...	×	
Cybele Loveni, Linnrs.	...	...	...	...	...	×			
Sphærexochus boops, Salt.	...	...	...	...	...	×	...	×	
Lichas laxatus, M'Coy	×	...	×	×	×	×	...	×	
Cheirurus bimucronatus, Murch.	...	...	...	...	...	×	...	×	
Cheirurus octolobatus, M'Coy	×	...	...	...	...	×			
Cheirurus juvenis, Salt.	...	...	...	...	...	×			
Trinucleus seticornis, Eaton	...	...	...	...	...	×	...	×	×
Trinucleus, var. *Bucklandi*, Barr.	...	...	...	...	...	×			
Trinucleus concentricus, Eaton	...	...	...	...	...	×	...	×	
Trinucleus fimbriatus, Murch.	×	...	×						

List of Fossils *(continued)*.

Names of Species.	α.		α & β.			α? & β.		β.	
	Foxhole.	Bronhaul.	Llandeilo-aber-Cowyn.	Clôg-y-frân Farmyard.	Moelden.	Llanddowror.	Clôg-y-frân Wood.	Trefanty.	Faynor.
Phacops apiculatus, Salt.	...	...	...	...	...	×			
Phacops truncato-caudatus, Portl.	...	...	...	...	...	×	...	×	
Phacops macroura, Sjögren	...	...	...	...	...	×			
Phacops Brongniarti, Portl.	...	...	...	...	...	×			
Asaphus Powisii, Murch.	×	...	...	...	...	×	...	×	
Ampyx tumidus, Forbes	...	...	...	...	...	×	×	×	
Ampyx rostratus, Sars	...	...	...	...	...	×	...	×	
Remopleurides sp.	...	...	...	...	...	×			
Acidaspis Brightii, Murch.	...	...	...	...	...	×			
Homalonotus bisulcatus	×	×	...	...	...	×	×	×	
Homalonotus rudis, Salt.	...	...	...	...	...	×	...	×	
Orthis calligramma, Dalm.	×	×	×	×	×	×	×	×	×
Orthis Actoniæ, Sow.	...	...	...	...	...	×	...	×	×
Orthis flabellulum, Sow.	...	...	...	...	...	×	...	...	×
Orthis porcata, M'Coy	...	...	...	...	...	×			
Orthis biforata, Schloth.	×	...	...	...	×	×	...	×	
Orthis elegantula, Dalm.	...	...	...	...	...	×	...	×	
Orthis testudinaria, Dalm.	×	...	×	×	...	×	...	×	
Orthis vespertilio, Sow.	...	...	...	...	...	×	...	×	
Orthis striatula, Emmons	...	...	...	...	...	×	...	×	×
Leptæna sericea, Sow.	...	×	...	...	...	×	×		
Leptæna transversalis, Wahl.	...	...	...	...	...	?			
Leptæna tenuicincta, M'Coy	...	...	...	...	...	×	...	×	×
Leptæna quinquecostata, M'Coy	...	...	...	...	...	?			
Strophomena rhomboidalis, Wilck.	×	×	×	×	×	×	...	×	×
Strophomena grandis, Sow.	×	...	×	...	...	×			
Lingula attenuata, Sow.	×	...	×	...	...	×			
Discina perrugata, M'Coy	...	...	...	...	...	×			
Siphonotreta micula, M'Coy	...	...	...	...	...	×	×	×	
Holopæa concinna, M'Coy	..	...	...	...	...	×	×		
Holopæa conica, Sow.	×	...	...	...	...	×			
Holopella cf. *tenuicincta*, M'Coy	...	...	...	...	...	×			
Turbo rupestris, Eichwald	...	...	...	...	...	×			
Murchisonia sp.	...	...	...	...	...	×			
Lituites cornu-arietis, Sow.	...	...	...	...	...	×	×	×	
Lituites anguiformis, Salt.	...	...	...	...	...	×	×		
Cyrtoceras sonax, Salt.	...	...	...	...	...	×	×	×	
Orthoceras vagans, Salt.	...	...	...	...	...	×	...	×	
Phragmoceras nautileum, Sow.	...	...	...	...	...	×			
Ecculiomphalus Bucklandi, Portl.	...	...	×	...	...	×	×		
Bellerophon bilobatus, Sow.	...	...	...	...	...	×	×		

At Foxhole, north of the Cywyn Valley, another good exposure occurs, where some quarrying operations have been carried on within recent years. The character of the beds is very similar to that of those exposed in the lower portion of the section at Llandeilo-aber-Cowyn, and the fossil-assemblage presents the same facies.

Reference has already been made to the dips at these two localities, and to the structure that they suggest (p. 627).

West of the River Tave the same beds are seen in a quarry near Bronhaul. This, probably, is Phillips's 'Upper Moor' fossil-locality. Fossils are fairly abundant and typical.

The narrow belt of folded-in beds of this age between Moelden and Llanddowror does not yield any fresh samples of the rock, and the weathered material is slightly different from that furnished by these beds elsewhere.

The beds are not typically exposed at Llanddowror. They are undoubtedly represented there, but not well developed.

At Clôg-y-frân, however, beds of Llandeilo-aber-Cowyn type are well seen in the farmyard, where they are faulted against *Didymograptus-bifidus* Beds and *Asaphus-tyrannus* Limestones (see p. 599). The beds are exposed, in a very rotten condition, near the pond; but fresh samples may be obtained from the lane in the field close by, and in the yard near the stables. They dip northwards at about 45°. Along the bottom of the yard higher beds, with abundance of typical fossils, are seen dipping under them. This is another indication of the overfold referred to above (p. 614).

Beds of the same age and of similar character are exposed behind the old cottage at Cwm-caedu. Here they are seen to succeed the black shales, and they pass up to the next stage in the vicinity. Fossils are not abundant, but the few that do occur are of the characteristic type.

(β) Sholeshook Beds.—These differ somewhat from those just described, in being much more arenaceous, and generally coarser in texture. On weathering, they produce sandstone of fair quality, but the material is often nothing better than loose sand. Fossils are, as a rule, very abundant.

The upper part of the section at Llandeilo-aber-Cowyn doubtless exposes beds of this age, but they are not so sandy.

At Foxhole, however, the succession is well seen. I availed myself of an opportunity to examine a continuous section from the Foxhole exposure to the old quarries on the brow of the hill near Trefanty, where the arenaceous beds have been much quarried in years gone by. Under ordinary circumstances, the relation of the two groups can be clearly made out here. These old quarries have yielded many fossils: big slabs have been seen which were covered with *Trinucleus seticornis*, His. and tails of *Cybele verrucosa*, Dalm.

These beds are well developed and extensively quarried at Llanddowror, 2 miles west of St. Clear's. They crop out along the brow of the ridge running in a north-westerly direction from the quarry—through the Gelli Wood, narrowing the valley of the Tave near Clôg-y-frân Bridge, and rising in a bold bluff on the north of the gorge—where they have been more or less extensively quarried. They cross the Tave a short distance south-west of Clôg-y-frân, a small exposure in the meadow indicating their strike, but they appear to be cut off by a fault at no great distance.

The beds are much exposed at Faynor, both in quarries and otherwise. They come out in the watercourse leading from the yard, past the well to the bottom of the dingle, where they are slightly disturbed by a fault which cuts them off a little to the south of this point.

About half way up the hill in the direction of Penlan Farm, they are again seen in a small quarry where they are nearly horizontal; but in the lane immediately to the north they dip northwards at a low angle. The upper beds are seen at Penlan, where they pass up into the next stage, the beds of which are here nearly horizontal.

A small patch is exposed at Parcau, about half a mile to the west. Here the beds dip gently south-westward, and pass up into the next stage immediately west of the yard.

(γ) Redhill Beds.—The arenaceous limestones are seen passing up into this stage near Clog-y-fran Bridge. The calcareous matter gradually disappears, forming, at last, merely small lenticular masses of sandy limestone in blue-grey shaly mudstones. The lenticles are generally full of fossils, but the mudstones themselves are very barren. These mudstones on weathering assume the characteristic olive-green colour. Fossils are usually rare all through them, except in isolated patches: that is, there are no continuous fossiliferous bands.

Rocks of this age are abundantly exposed in the south of the anticline, and are readily distinguishable from those below; but to fix their exact upward limit is not an easy matter, if at all possible.

At Parc-y-graig, north of Foxhole, a small section of these beds is seen in the bank of the Tave, but fossils are very rare here. Only a few specimens of *Orthis* and crinoid-fragments occur. Abundant débris is seen on the hill south of Pant-dwfn, under conditions which assist in locating the fault that brings the beds against *Dicranograptus*-Shales (p. 629).

On the west of the Tave the beds are exposed near Morfa-bach in two small quarries. In the smaller and lower quarry the beds are of the usual type, and fossils are rare. A few stray specimens of *Leptæna sericea*, Sow. and fragments of *Favosites* occur. This section is fairly high up in the series. In the upper quarry are bands of weathered limestone, containing crinoid-fragments. There is a small thrust from the north shown in section here, and it is suggested that the calcareous beds belong to a higher stage.

In the yard at Lower Cresswell is a small exposure, which has yielded a good number of fossils, including:—

Favosites fibrosa, Goldf.
Ptilodictya dichotoma, Portl.
Hemicosmites rugatus, Forbes.
Illænus Bowmanni, Salt.
Trinucleus concentricus, Eaton.
Trinucleus cf. *seticornis*, Eaton.
Homalonotus sp.
Calymene sp.
Orthis calligramma, Dalm.
Orthis biloba (?) Linn.
Orthis elegantula, Dalm.
Orthis testudinaria, Dalm.
Leptæna sericea, Sow.
Orthoceras gracile, Portl.; etc.

The beds are also frequently exposed near Moor, Tadil, and Maesygrove. In the watercourse between the latter place and Moelden, the beds are traceable to within a short distance of the *Dicranograptus*-Shales, indicating pretty nearly the locality of the fault. The beds are also well seen at Maeslan and in the Pen-y-graig and Cwmdwr lane, dipping northwards at both places, and broken by faults seen in section in the lane.

Near Talfan Cottages is a small quarry on the roadside, where the beds are somewhat coarser in grain and dipping northwards. They are faulted against lower beds on the north and south, in the immediate vicinity. *Favosites fibrosa*, Goldf.; *Phacops* cf. *macroura*, Sjögren; *Trinucleus concentricus*, Eaton; *Orthis calligramma*, Dalm., etc. occur here.

The lane leading to Talfan affords a continuous exposure, but fossils are very rare. Here the beds are faulted on the south against *Dicranograptus*-Beds, and on the north, a short distance from the farmyard, against Sholeshook Limestone (β).

There are several exposures near Felin-ban. The one on the road leading to Cnycau shows the beds in contact with the Old Red Sandstone, and dipping southwards at a high angle. It is probable that a small thickness of beds of the next stage is present here. The character of the rock and the fossils suggest as much.

A quarter of a mile up the road the Llanddowror limestone comes out with a low southerly dip. This is seemingly a portion of the Llandeilo-aber-Cowyn anticlinal fold. The ground is, however, much cut up by faults about here.

At the entrance to Penlan the beds are almost horizontal. An exposure of 200 yards or more along the road in the direction of Cnycau shows the gradual steepening of the dip, but fossils are very rare.

West of Parcau the beds are frequently exposed. Sections are seen in the lane leading to Pont Parcau. The few fossils that do occur are of the usual type.

Exposures are abundant near Penlan, Faynor, and Pentrehowel, and in the woods near Teiau-bach. The road-exposure west of Pentrehowel has yielded

Favosites fibrosa, Goldf.
Ptilodictya dichotoma, Portl.
Trinucleus concentricus, Eaton.
Illænus sp.
Orthis calligramma, Dalm.
Orthis flabellulum, Sow.
Orthis biforata, Schloth.
Leptæna sericea, Sow.
Cyrtoceras sp.

The beds occur also at Clôg-y-frân, where they are much disturbed by folding and faulting. Along the lane to the south the dip continually varies, and a little fold is seen in section in a small exposure in the field at the bend in the road. A few yards to the south-west the beds are faulted against the arenaceous limestones, having been thrown down quite 100 feet. Fossils collected in this locality include:—

Favosites fibrosa, Goldf.	*Orthis calligramma*, Dalm.
Hemicosmites rugatus, Forbes.	*Orthis elegantula*, Dalm.
Hemicosmites oblongus, Pander.	*Orthis testudinaria*, Dalm.
Petraia sp.	*Orthis biforata*, Schloth.
Crinoid-fragments.	*Leptæna sericea*, Sow.
Calymene cf. *Blumenbachii*, Brongn.	*Leptæna tenuicincta*, M'Coy.
Phacops cf. *Brongniarti*, Portl.	*Ecculiomphalus Bucklandi*, Portl.;
Homalonotus bisulcatus, Salt.	etc.

(δ) Slade Beds.—These beds are well represented in the area, but the line separating them from those of the stage below cannot be drawn with any degree of confidence, the upward passage being very gradual and devoid of any definite dividing-break. The mudstones and shales are undistinguishable from those of the Redhill Series, but the bands of limestone (usually weathered) which occur in them, and the typical assemblage of fossils in the higher part, are the only indications available that the higher stage has been reached.

It is very probable that beds of this age occur near Heol-down, and Lower Cresswell, and also on Maesgwrda Hill, but there is no satisfactory exposure. There is, however, a good little section in an old quarry west of Cwmdwr, near Llanddowror, where some bands of calciferous shales and mudstones are exposed. The rock is much crushed, and dips south-westwards. Some bands are crowded with *Favosites fibrosa*, Goldf. and *Phyllopora Hisingeri*, M'Coy. Other fossils occurring here are:—

Crinoid-fragments.	*Glauconome disticha*, Goldf.
Tentaculites anglicus, Salt.	*Strophomena rhomboidalis*, Wilck.
Illænus sp.	*Leptæna sericea*, Sow.
Calymene Blumenbachii, Brongn.	*Orthis elegantula*, Dalm.; etc.
Trinucleus seticornis, Eaton.	

There are several good exposures near Redgate; one in the wood to the north shows one of the bands of limestone, which is very rotten here, but crowded with fossils.

The same beds come out on the main road, at the first rise to the west. These sections have yielded crowds of *Favosites fibrosa*, Goldf. and *Phyllopora Hisingeri*, M'Coy: *Trinucleus seticornis* is also very common. Other fossils collected here are:—

Glyptocrinus basalis, M'Coy.	*Strophomena rhomboidalis*, Wilck. (abundant).
Tentaculites anglicus, Salt.	*Leptæna sericea*, Sow.
Calymene Blumenbachii, Brongn.	*Leptæna quinquecostata*, M'Coy.
Illænus Murchisoni, Salt.	*Orthis calligramma*, Dalm.
Illænus Bowmanni, Salt.	*Orthis testudinaria*, Dalm.
Trinucleus concentricus, Eaton.	*Orthis porcata*, M'Coy.
Glauconome disticha, Goldf.	*Orthis elegantula*, Dalm.

The same bands are again exposed near Pant-y-iar, where fossils of the usual type are fairly abundant.

At Cnycau there is a roadside section showing some very fossiliferous mudstones and bands of rotten shelly limestones.

The former contain crowds of *Leptæna sericea*, Sow.; and the latter are almost entirely composed of *Orthis*, chiefly *O. testudinaria*, Dalm.

These bands come out on the western side of Cwm-pâl and in the wooded ground near Dol-dderwydd. One band in particular, composed of crowds of *Orthis*, is seen in the Old Pale lane, where it reaches the top of the hill: this is probably the same as the Cnycau *Orthis*-limestone. The fossils collected from it are:—

Orthis testudinaria, Dalm.
Orthis biforata, Schloth.
Orthis calligramma, Dalm.
Orthis elegantula, Dalm.
Leptæna quinquecostata, M'Coy.

Forest Tunnel has been excavated in beds of this age, and here some of the limestone-bands are unweathered and full of fossils. The dip here is almost vertical, and the beds are faulted against *Didymograptus-bifidus* Beds on the north and against striped Lower Llandovery (?) Flags on the south. The beds are traceable for about 200 yards westward, on both sides of the Tave, and then they disappear entirely, being cut off by a fault. The fossils include:—

Favosites fibrosa, Goldf.
Phyllopora Hisingeri, M'Coy.
Petraia sp.
Tentaculites anglicus, Salt.
Calymene Blumenbachii, Brongn.
Illænus sp.
Trinucleus seticornis, Eaton.
Trinucleus concentricus, Eaton.
Strophomena rhomboidalis, Wilck. (very abundant).
Strophomena corrugatella, Dav.
Leptæna sericea, Sow.
Orthis biforata, Schloth.
Orthis testudinaria, Dalm.; etc.

A slice of these beds has been faulted down among *Didymograptus-bifidus* Beds at Forest: they are exposed at Forest Farmyard, and at intervals between that place and a point south of Pant-y-gwenyn. The fossils (which abound) are of the Tunnel type.

(2) North of the Anticline.

The black slaty *Dicranograptus*-Shales are succeeded, north of the anticline, by brown-grey mudstones, grits, and sandstones, in all of which fossils are extremely rare—a few specimens of *Orthis* being all that has been discovered in them. They possess no character in common with the beds that succeed the *Dicranograptus*-Beds on the south. They are somewhat like beds of the Redhill stage, but much more like the Great Pale beds which will be dealt with below. Their age must remain therefore an open question, till further work has been done among them and more fossils discovered.

(*g*) Lower Llandovery (?) Rocks.

The last series (δ) of beds pass up into conglomerates, grits, and sandstones, with blue-grey mudstone partings. The conglomerates are seen *in situ* at Pant-y-mwswm, and are here about 8 feet thick. These are succeeded by grits and grey sandstones, well exposed at Greystones. There are very few localities where these beds can be seen in place, but their outcrop can be readily traced by means of abundant loose blocks and débris. This strikes a more or

less irregular curve along the eastern brow of 'Pale Mountain,' between Greystones and Dol-dderwydd, where the beds are cut off by a fault.

Members of the series are seen near Forest Tunnel and in the wooded ground north of Great Pale. A thin band of mudstones cropping out in the wood has yielded some fragments of fossils including *Orthis*, *Atrypa (?)*, and trilobites (*Acidaspis Brightii?* and *Trinucleus ?*).

The grits have been quarried in Pale Wood and at Penygraig. West of the latter place they are either faulted out, or overlapped by the Old Red Sandstone; but they are well exposed again in Middleway Dingle and in Penyback Quarries, south of Whitland. In the quarries the beds are vertical, and exhibit beautiful samples of ripple-marks, which give a clue as to the conditions under which they were laid down. Fossils are extremely rare in these beds—so much so, that with the exception of the specimens found in Pale Wood, only one or two poor unidentifiable fragments have been discovered.

Whether these beds are of true Lower Llandovery age has not been definitely settled; but it is quite clear that they are younger than the Bala rocks of this region, and older than the Old Red Sandstone, under which they are seen to pass at several points.

IV. Concluding Remarks.

It is deemed unnecessary to take up any space for correlation, for most of the beds agree closely with the beds of other Welsh areas, which have been carefully and fully worked out by various authors.

The *Tetragraptus*-Beds are, in most respects, in complete agreement with those beds at St. David's, the fauna at Blaencediw being identical with that found at Whitesand Bay (Miss Elles).

The *Didymograptus-bifidus* and *D.-Murchisoni* Beds of this region are, lithologically, very similar to those beds as exposed at Llanvirn and Abereiddy, and the two faunas are practically identical.

The *Asaphus-tyrannus* Beds, although varying much in lithological character, agree palæontologically with beds of that age in the typical areas of Llandeilo and Pembrokeshire.

The *Dicranograptus*-Beds are like those of Pembrokeshire in some respects, but there is one feature that calls for special remark. Miss Elles says that *Leptograptus*-Beds were not known to occur in South Wales till they were discovered at Mydrim. These beds, she says, are on the same horizon as the Rorrington Flags of Shropshire.

The three lower members of the Bala-Caradoc Series of this area are so like the Robeston-Wathen, the Sholeshook Limestones, and the Redhill Beds of Messrs. Marr & Roberts, that they could hardly be mistaken by anyone that had seen those beds in Pembrokeshire. There is, however, a slight lithological difference between the fourth member (δ) and the Slade Beds of Haver-

fordwest. Yet their relative position, general character, and fossil-contents render their identification fairly certain.

The beds to which a Lower Llandovery age has been assigned, being singularly barren, are like beds of that age elsewhere in their very barrenness. I feel convinced that their proper place has been allotted to them, but cannot satisfactorily express the reasons that form the basis of this conviction.

Some work on the belt of ground that lies to the north of the area now described will, it is believed, throw much light on this matter.

In conclusion, I desire to state that when this work was in its earlier stages I received much valuable advice from the late Dr. Henry Hicks, F.R.S. I also desire to express my indebtedness to Miss G. L. Elles, D.Sc., who very kindly examined and identified some of my graptolites, and made valuable suggestions as to the age of the rocks from which the graptolites had been collected.

It is right that I should also express my obligations to those landowners and landholders who very kindly and readily granted me permission to go over their land, and otherwise helped me with the work; also to many farmers and others who rendered me assistance with pick and spade, and in collecting a large number of fossils.

EXPLANATION OF PLATE XLVI.

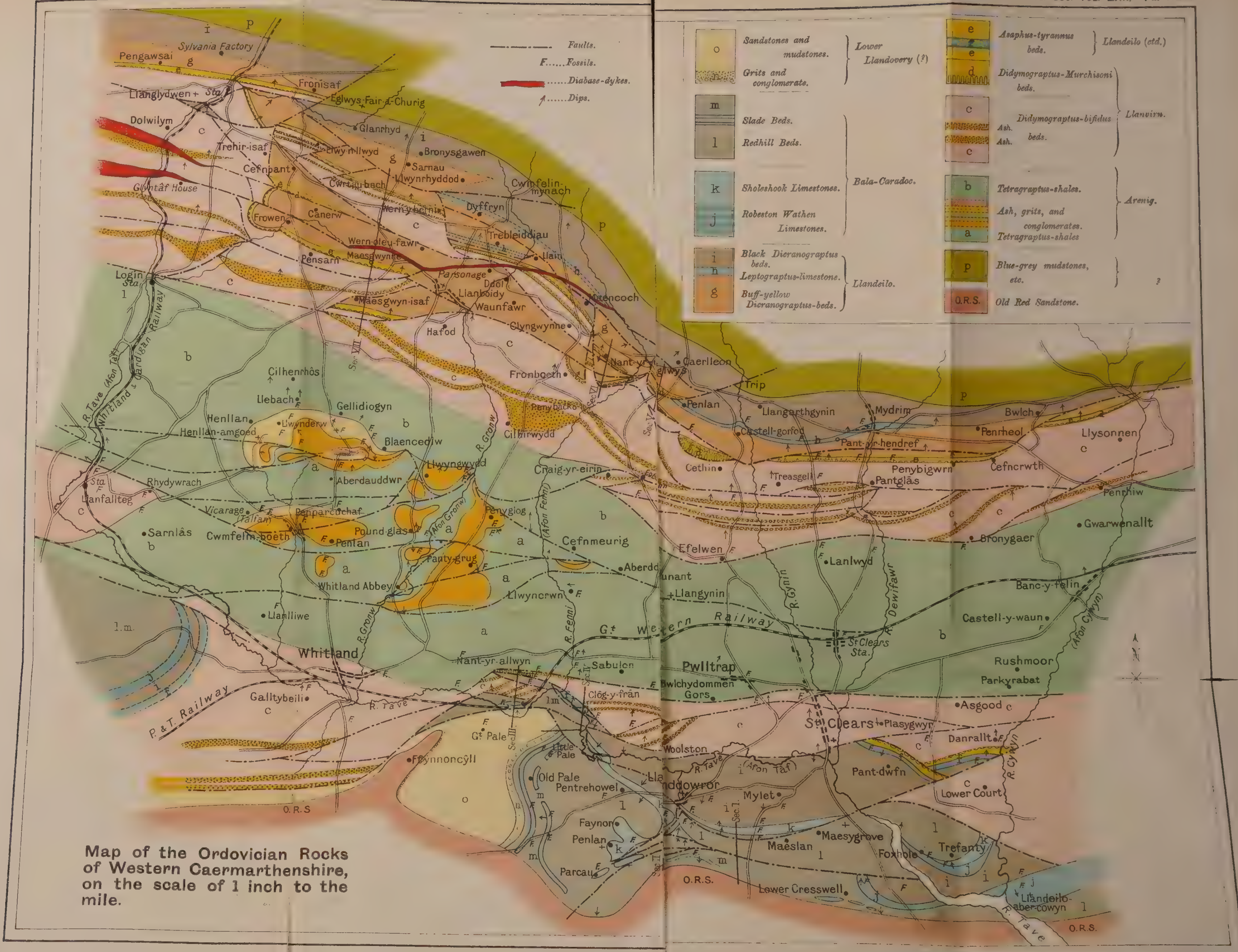
Map of the Ordovician rocks of Western Caermarthenshire, on the scale of 1 inch to the mile.

Discussion.

The Chairman (Mr. A. Strahan) considered that this paper showed evidence of long and careful work in the field. Almost unassisted, the Author had succeeded in identifying the zones and unravelling the structure of a most complicated bit of Ordovician ground. When the officers of the Geological Survey entered the region in 1903, he not only placed all his knowledge at their disposal, but continued his work in close association with them—to their great mutual advantage. Pressure, however, had been put upon him to bring his results before the Geological Society of London, and thus get full credit for his own researches.

The ground which the Author had examined was partly the same as that described in a paper compiled by Dr. Marr from notes left by the late Mr. Thomas Roberts, and published in the Quarterly Journal in 1893. Roberts's work, so far as it went, was excellent, but he had made no more than a commencement of his investigation of the district when he died.

Mr. T. C. Cantrill thought that one of the most important points in the paper was the identification of *Nemagraptus gracilis* in the limestone which, at Mydrim, separates the brown-weathering *Dicranograptus*-Shales below, from the black *Dicranograptus*-Shales



Map of the Ordovician Rocks of Western Caermarthenshire, on the scale of 1 inch to the mile.

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above. This discovery by the Author appeared definitely to prove the presence in South Wales of beds of Glenkiln age, and suggested the possibility of the shales overlying the limestone being referable to the Hartfell Group. The Author's record of *Dicranograptus Clingani* from these beds tended to confirm that supposition.

The Author placed the Robeston-Wathen Limestone below that of Sholeshook, and regarded them as calcareous developments of the *Dicranograptus*-Shales and Redhill Beds respectively; and this was in agreement with the view expressed by Marr & Roberts in their paper on the Haverfordwest district.

Miss G. L. Elles remarked on the great skill shown by the Author in the working-out of a complicated area. He had submitted some of his graptolites to her, and the evidence afforded by them merely confirmed the results arrived at by him on independent grounds.

With regard to the question as to how much of the *Dicranograptus*-Shales should be regarded as of Bala (Hartfell) age, she was inclined to think that a considerable portion of them contained a fauna more allied to that of the Llandeilo (Glenkiln). There appeared to have been some confusion between *Dicranograptus rectus*, a characteristic and common Glenkiln form, and *Dicranograptus Clingani*, an equally-characteristic but far less common Hartfell species; hence beds containing a typical Glenkiln fauna seemed in some cases to have been relegated to too high an horizon.

Mr. H. H. Thomas, in reply, thanked the Fellows on behalf of the Author for their kind reception of the paper; he agreed with Mr. Cantrill and previous speakers on the great importance of the Author's work in so complicated a district. The Author fully realized the great value of Thomas Roberts's work, which had been of considerable assistance to him. The Author had submitted to the speaker specimens of the igneous rocks from Llanboidy and Dolwilym, which are both ophitic diabase. The Llanboidy rock is very much decomposed; but the Dolwilym rock is much fresher, and is characterized by the presence of pseudomorphs after a rhombic pyroxene, a mineral not very common in the Pembrokeshire minor dykes. It is likely that these masses belong to the same intrusion, but this is impossible of proof, except from a study of the field-relations.

29. *The* Tarannon Series *of* Tarannon.

By Ethel M. R. Wood (Mrs. G. A. Shakespear), D.Sc., University of Birmingham. (Communicated by Prof. C. Lapworth, LL.D., F.R.S., F.G.S.
Read February 21st, 1906.)

[Plates XLVII & XLVIII—Map & Sections.]

Contents.

I. Introduction.

(A) Historical Review.

Stretching southward for 70 miles from the shores of the Irish Sea near Conway in North Wales, through Denbighshire and Montgomeryshire into the central parts of Radnorshire near Llanbister, there sweeps a continuous band of massive greywackés, flagstones, and shales, known to geologists as the Denbighshire Grits or Flags. This arenaceous formation is from 1000 to 3000 feet in thickness, and is acknowledged on all hands to be of Wenlock age.

Rising out from beneath the Denbighshire Grits, and intervening between them and the older rocks which are at present assigned to the Llandovery and Bala, there occurs a series of relatively shaly strata which are distinguished on the Geological-Survey maps by a special tint of purple, and are indicated upon the legends as 'Tarannon Shales.' They are laid down on the maps as forming a narrow belt, seldom exceeding a quarter of a mile in width and entering into all the sinuosities of the outcrop of the lower margin of the Denbighshire Grits.

Although these so-called 'Tarannon' Beds were not mapped as constituting a distinct formation until 1855, their peculiar mineral characters—'fine, smooth, slaty strata, grey or light blue, occasionally slightly sandy, and alternating with purple bands'[1]—had not escaped the attention of the earlier geological workers in Wales. As early as 1843 Sedgwick and Salter had noticed in the Berwyn

[1] Sir Andrew Ramsay, 'Geology of North Wales' Mem. Geol. Surv. vol. iii (1866) p. 207.

Hills certain 'pale-coloured earthy slates' which 'seem to pass without a break into the overlying Denbigh Flagstone.'[1] From the fact that they were aluminous and readily disintegrated these 'slates' were often referred to in the field by Sedgwick as the 'paste-rock.'[2] At that time he and Salter regarded them as 'beds of passage' between the Cambrian and Silurian.

In the year 1854, however, Sedgwick having arrived at the conclusion that, in the Berwyn Hills and elsewhere, there was an unconformity between his Cambrian and Silurian systems marked by the absence of the May Hill Sandstone, relegated these 'paste-rocks' to a lower horizon, and placed them 'very nearly at the crown of the whole Cambrian series,'[3] that is to say at the top of the Bala formation.

In the 1st edition of the Geological Survey maps of Wales (1850) no attempt was made to show these 'pale slates' as a distinct formation, and they were included in the ground coloured as Bala. At a later date, however, Jukes & Aveline,[4] observing them to pass naturally upwards into the Wenlock and Denbigh Beds, came to the conclusion that they belonged rather to the Wenlock formation and were therefore of Upper Silurian age.

In the further survey of Wales (1855) Aveline discovered proofs that what appeared to be similar 'pale slates' rise out from below the Wenlock Shales farther south, namely, near Newbridge, west of Builth, and near Llandovery; at both of these localities they follow conformably upon Upper Llandovery strata. This led Aveline to regard the 'pale slates' as a distinct formation, and to map them as a practically-continuous band all along the western border of the Wenlock Shales and Denbighshire Grits, from Conway on the north to Llandeilo on the south. He indicated them on the maps by a special tint of colour, and named them 'Tarannon Shales,' from the river-valley of Tarannon in Montgomeryshire where they were well developed. In this district of Tarannon he inferred that they follow unconformably on Lower Llandovery shales and grits.

Although the band coloured as 'Tarannon Shales' was thus laid down upon the maps and sections of the Geological Survey in 1855, it was not until 1866, when the 1st edition of Ramsay's 'Geology of North Wales'[5] was published, that any official description of these beds appeared. In that work the characters and relationships of the 'Tarannons' throughout Wales were described, and their thickness was estimated at 1000 to 1500 feet. Their stratigraphical position, as then understood, may be summarized in Ramsay's own words:—

'In the country near Llandovery (Noeth Grug, etc.) and west of Builth the shales lie directly, and apparently conformably, on the Upper Llandovery Beds. A little further north the Tarannon Beds overlap the Upper Llandovery strata, and between that point and the mouth of the Conway in North

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[1] Quart. Journ. Geol. Soc. vol. i (1845) p. 14.
[2] Phil. Mag. ser. 4, vol. viii (1854) p. 307, footnote. [3] *Ibid. loc. cit.*
[4] 'The Geology of North Wales' Mem. Geol. Surv. vol. iii (1866) p. 4.
[5] *Ibid.* pp. 16, 207–208.

Wales they lie transgressively and quite unconformably on various members of the Lower Silurian Series. On the other hand, both in Wales and Shropshire, they pass conformably under the lowest beds of Wenlock Shale, with which undoubtedly they are intimately connected.'

Beyond an occasional reference to the 'Tarannon Shales' in various memoirs and text-books, no subsequent stratigraphical account of this band has been published.

Thus, if we rely solely upon the descriptions and maps of the Geological Survey, the 'Tarannon Shales' as a group must be younger than the Upper Llandovery and older than the Wenlock Shale. But whether these 'Tarannon Shales' answer to the whole or only to a part of the period intervening between the Upper Llandovery and Wenlock, or whether their alliances are more with the former than with the latter, or *vice versa*, are questions which cannot be determined from the stratigraphical evidence hitherto published.

Neither at the time when the 'Tarannon' Beds were originally mapped, nor for many years after, were any fossils obtained from these rocks. It was impossible, therefore, for the geologist either to estimate their systematic range in geological chronology, or to recognize their equivalents elsewhere.

Southern Scotland.—The first light upon the palæontological side of the question came from Scotland. In the year 1870 Prof. Lapworth[1] described a massive series of strata, overlying the Black Shales of Moffat and characterized by a special graptolitic fauna, under the title of the Gala Group. He divided this group into :—(1) Abbotsford Flags, (2) Gala Grits, (3) Buckholm Grits, and (4) Grieston Beds. Founding his correlation on the view (then generally received) of the Upper Llandeilo age of the underlying Moffat Shales, he assigned the Gala Group to the Caradoc or Bala.

In the year 1878[2] he published the results of his graptolitic zonal work on the Moffat Series, showing that it included not only the Upper Llandeilo but also the Caradoc and Lower Llandovery. Thus he carried up inferentially the base of the Gala to the Upper Llandovery; and, further, since he had already shown in his paper on the Scottish Monograptidæ[3] that the highest beds of the southern representative of this Gala Group (Hawick Beds) pass up conformably into the Riccarton (Wenlock) Beds, the Gala Group as a whole should not only include the Upper Llandovery, but also the representatives of the Tarannon.

In the year 1879 Prof. Lapworth[4] discovered fossils in the band of 'Tarannon Shale' of the Geological-Survey maps at Conway (North Wales), and these forms included several of the graptolites

[1] Trans. Edin. Geol. Soc. vol. ii (1869–74) p. 46, & Geol. Mag. vol. vii (1870) pp. 204–209 & 279–84.

[2] Quart. Journ. Geol. Soc. vol. xxxiv (1878) pp. 240, etc.

[3] Geol. Mag. dec. ii, vol. iii (1876) pp. 308, etc.

[4] Ann. & Mag. Nat. Hist. ser. 5, vol. v (1880) p. 367, & vol. vi (1880) pp. 200 & 204.

characteristic of his Lower Gala Group of the South of Scotland, as distinct from those of the Moffat Shales (Upper Llandeilo–Llandovery) below, and the Riccarton (Wenlock) Beds above. Therefore, in the following year (1880), he was able to assert, in his paper on the 'Geological Distribution of the Rhabdophora,' that the

'Tarannon Shale of Wales . . . . occupies the systematic place of the Gala Group, to which, however, it is vastly inferior in vertical thickness and in the richness and variety of its graptolite-fauna.' (*Op. cit.* vol. v, p. 367.)

In the Table at the end of that paper (vol. vi, p. 204) he assigns the whole of the Gala or Queensberry Group and its equivalents in Girvan to the Tarannon age, and divides the Scottish Tarannon rocks into three graptolitic zones (*op. cit.* p. 200):—(1) *Rastrites maximus*, (2) *Monograptus exiguus*, and (3) *Cyrtograptus Grayæ*; the first of which he considers 'must be regarded as the zone of transition' between the Tarannon (Gala) and the preceding Llandovery (Birkhill) formations. These views have subsequently been generally adopted by stratigraphists—with the exception, however, that in most stratigraphical papers the zone of *Rastrites maximus* is wholly assigned to the Upper Birkhill.

But here it must be borne in mind that the assignation of these three graptolitic zones to the Tarannon age was, to a certain extent, a matter of inference, based mainly upon the facts that Lower Gala fossils had been found at Conway and that the zone of *Cyrtograptus Murchisoni* constituted the base of the Wenlock at Builth and elsewhere.

North Wales.—A certain amount of additional light was thrown upon the position of the 'Tarannon Shale' by the palæontological discoveries in the older Llandovery and the newer Wenlock Beds in North Wales.

In 1880 Dr. Marr[1] reported Birkhill graptolites from the beds immediately underlying the strata mapped as Tarannon Shales at Cerrig-y-druidion.

At a later date (1893) Mr. Lake and Prof. Groom recorded Birkhill graptolites from the strata underlying the 'Tarannon Shales' in the Corwen district; and in the following year (1894) Mr. Lake demonstrated the conformity of the local Tarannon to the overlying Wenlock Beds with *Cyrtograptus Murchisoni*.[2]

In 1895 the 'Tarannon Shales' of Conway were re-examined by Miss Elles and myself[3] and were found to contain the distinct faunas of the two zones of *Rastrites maximus* and *Monograptus exiguus*. No trace, however, was found of an Upper Gala fauna, although *Cyrtograptus Murchisoni* was found in the Wenlock Beds above.

[1] Quart. Journ. Geol. Soc. vol. xxxvi (1880) pp. 277, etc.
[2] *Ibid.* vol. xlix (1893) p. 426, & vol. li (1895) p. 9.
[3] *Ibid.* vol. lii (1896) pp. 273, etc.

Central Wales.—Turning now to Central Wales, we find that the whole of the country lying west of the outcrop of the 'Tarannon-Shale' band, as far as the coast of Caerdigan Bay, is shown upon the Survey-maps to be occupied by strata coloured as of Lower Llandovery and Bala age. The rocks of this great range of country were first described in outline by Sedgwick[1] (1847), and were divided by him into three groups:—the Aberystwyth Beds on the west, the Plynlimmon Grits in the centre, and the Rhayader Slates on the east; but no boundaries were laid down between these three divisions, and no fossils were recorded from them.

The first important piece of palæontological work in these beds of Central Wales was done by Walter Keeping[2] in 1880. He adopted in the main the three great geographical divisions of Sedgwick, but divided the Plynlimmon Grits into two groups—a lower or Metalliferous Slate group and a higher, the Plynlimmon Grits. In the Aberystwyth Grits and Metalliferous Slates he discovered numerous graptolites, which were identified by Prof. Lapworth and shown to be characteristic of the Upper Birkhill Beds of the South of Scotland. Keeping, therefore, was of the opinion that nearly the whole of Central Wales was made up of rocks of Upper Llandovery age, much folded and contorted, and he suggested that the Plynlimmon Grits and underlying Rhayader Pale Shales which overlay the Metalliferous Slates at Rhayader should be assigned to the Tarannon horizon.

In the course of his researches in Central Wales, Keeping visited the Llanbrynmair-Tarannon district and briefly described the succession of the beds there exhibited. He recognized three main groups:—

(1) The Denbighshire Grits at the top.
(2) The Tarannon Shales, in which he discovered some 'obscure fragments of graptolites.'
(3) The Metalliferous Group, fully developed in the Pennant Valley and containing characteristic Upper Birkhill fossils.

He observed that, in this district, the 'Tarannon Shale' is separated from the Metalliferous Group by a zone of grits (Lower Llandovery Grits of the Geological Survey), which he found difficulty in correlating with the other main grit-masses of Central Wales, namely, the Aberystwyth and Plynlimmon Grits. He regarded them as a local and arenaceous upper part of his Metalliferous Group, and he agreed with the Survey in considering that an unconformity existed between them and the Tarannon.

The most important recent work on the beds of Central Wales is that by Dr. Herbert Lapworth,[3] who in 1899 discovered in the neighbourhood of Rhayader, following on local Bala rocks, three distinct stratigraphical groups—(1) the Gwastaden, which he assigned to the Lower Llandovery, (2) the Caban to the Upper Llandovery, and (3) the Rhayader Pale Shales to the Gala-Tarannon. His Lower

[1] Quart. Journ. Geol. Soc. vol. iii (1847) pp. 152–53.
[2] *Ibid.* vol. xxxvii (1881) pp. 141, etc.
[3] *Ibid.* vol. lvi (1900) pp. 67, etc.

Llandovery contained the graptolitic zones of the Lower Birkhill of Scotland, his Upper Llandovery those of the Upper Birkhill (with the exception of the zone of *Rastrites maximus*), while the Rhayader Pale Shales which followed contained fossils of the zones of *Rastrites maximus* and of *Monograptus exiguus*.

Summarizing the facts and conclusions hitherto arrived at with respect to the 'Tarannon' in Wales, we may regard it as established that the 'Tarannon-Shale' formation, as shown on the Geological-Survey map at Conway, includes the zones of *Rastrites maximus* and *Monograptus exiguus*, and that the lowest graptolitic zone of the succeeding Wenlock formation throughout Wales is that of *Cyrtograptus Murchisoni*. As yet, however, we have no proof that the 'Tarannon' contains the third and highest graptolitic Gala zone, namely, that of *Cyrtograptus Grayæ*; nor do we know whether the 'Tarannon-Shale' band, as mapped, includes strata of the same age all along its course. Further, the discovery of Dr. Herbert Lapworth in the 'Pale Shales' of Rhayader of the two fossiliferous zones which mark the 'Tarannon Shale' of Conway, far to the south and west of the band mapped as Tarannon in Central Wales, carries with it the implication that here the Tarannon extends much farther westward than is shown on the published maps.

About midway along the course of the 'Tarannon' band, and south-east of the village of Llanbrynmair, a long promontory formed of Denbighshire Grits and 'Tarannon Shale' is mapped as running out from the main mass of Denbighshire Grits and extending southward from Llanbrynmair to Stay-a-little, a distance of some 6 miles. This is shown by the outcrops and dips to be a syncline, its centre being occupied by Denbighshire Grits and its flanks by the 'Tarannon,' while the surrounding and underlying strata are mapped as continuous with the so-called 'Lower Llandovery,' which spreads out over the main part of Central Wales.

As in this district the 'Tarannon Shales' fringe the Denbighshire Grits on its eastern, western, and southern borders, there is per unit of area a greater length of boundary-line available for study than anywhere else along the course of the 'Tarannon' band. Further, this ought to be regarded as the typical area of the 'Tarannon Shales,' for they received their name from the small river of Tarannon, which rises near the centre of this basin-shaped outlier and flows south-eastward down its longer diameter. And, finally, not only is this Tarannon promontory important as being the area where we should presumably expect to find the typical development of the 'Tarannon' strata; but here the sequence appears from the map to be of more than ordinary simplicity, while the physical features afford especially-favourable opportunities for the study and examination of the rocks in the field.

On these grounds Prof. Lapworth selected this district, many years ago, as that in which the detailed lithological and palæontological succession of the 'Tarannon' formation should be sought for; and, after the publication of Dr. Herbert Lapworth's paper on the

Silurian Sequence of Rhayader, he suggested that I should take up this special Tarannon work.

For the last four years I have spent my available leisure in working out the stratigraphy of this Llanbrynmair-Tarannon area, and in collecting and identifying the fossils of its recognizable zones. The present paper embodies the results that I have obtained in the district.

(B) The Tarannon District.

(1) General Topography.

The Llanbrynmair-Tarannon district, as described in the present paper, includes an area which covers some 22 square miles. It is well defined on two sides by physical features. Its western margin is constituted by the valley of the Afon Twymyn, a river which flows almost due north for a distance of nearly 6 miles from Dyliffe to Llanbrynmair Station, at which place it turns abruptly westward to join the Dyfi at Cemmaes Road. Its north-eastern margin is formed by the transverse valley of the Afon Iaen, a tributary of the Twymyn, and along this valley run the main road and the railway from Llanbrynmair to Carno. The south-eastern margin, on the other hand, is a purely-arbitrary one as regards physical features, and may be roughly defined by a line drawn from the New Inn, Stay-a-little, to Carno across the hills of Esgair-drain-llwyn.

The central part of the district is occupied by an elevated tableland, which is cut off from the main tableland of the Denbighshire Grits on the north by the transverse valley already mentioned. It is intersected by a second transverse valley which partially separates the heights of Newydd Fynyddog on the north from the moors of Tarannon proper on the south. This tableland attains in a few places an elevation of 1600 feet, and forms a rolling upland covered for the most part with coarse grass, the monotony being broken here and there by rocky exposures, dry stretches of bracken and heather, peat-stacks, or rushy hollows where the spongy moss stores up the rainfall in treacherous bogs. Flocks of sheep find pasturage on the moorland, and the loneliness of the scene is relieved by an occasional farmhouse nestling on the sheltered sides of the valley.

Everywhere along its western side the Tarannon moorland plateau descends abruptly into the well-wooded and cultivated valley of the Twymyn the slope being sometimes rounded and grass-covered, sometimes precipitous and craggy. But westward beyond the valley of the Twymyn rise the bare crags of the 'Pennant Metalliferous Slates,' gloomy and forbidding, with long slopes of barren scree stretching down to the river, and forming a marked contrast with the green restful undulations of the Tarannon Hills to the eastward.

North of the Tarannon moorland rises Newydd Fynyddog. This is a fine heather-clad height falling abruptly on all sides, especially on its northern face, where it descends through bracken-

covered and wooded steeps into the narrow valley of the Afon Iaen.

All along the north-eastern side of the area, towards Carno, however, the slopes are less conspicuous, and on the whole more gentle.

To the south the Tarannon moorland continues in an unbroken stretch, far beyond the limits of this district.

The district is well watered, and abundant rock-sections are exposed both in the more open valleys of the main rivers and in the gorge-like clefts of their smaller tributaries. As already indicated, the western and northern slopes of the tableland are drained by the Twymyn and Iaen respectively, these being tributaries of the Dyfi. From the southern and western declivities, on the other hand, the water flows through the rivers Clwyddog, Tarannon, and Garno, and their tributaries into the Severn. Thus a line passing in a direction from north-north-east to south-south-west across the northern end of the Tarannon tableland forms part of the watershed separating the two important river-systems of Caerdigan Bay and the Bristol Channel.

(2) General Geology.

The rocks of the Tarannon district are, on the whole, of the usual greywacké type. They consist mainly of shales and mudstones, varying in colour from light grey to black, with occasional bands of pale green and purple. These are interstratified, however, with more arenaceous beds—greywacké-flags, felspathic and quartzose grits—ranging in thickness from a fraction of an inch up to 4 or 6 feet. The grits are, for the most part, fine in texture, and are nowhere coarse enough to be termed conglomerates. The monotonous pale and dull colour of the beds is relieved by the weathering of many of the shales, mudstones, and grits to reddish brown and brilliant orange, due to the amount of iron present in the rocks.

Considered as a whole, the geology of the district is fairly simple. The highest beds met with are the grits and flags of the Denbighshire Series, which spread out in gentle undulations over the central and northern parts of the tableland. These pass down into shales and mudstones containing typical Wenlock fossils. Immediately underlying these, apparently with complete conformity, come certain pale-green mudstones with one, two, or three bands of a bright maroon colour, and occasional flaggy beds. These are the local Tarannon Shales, as here mapped by the Survey. The shales in their turn pass down, also with apparent conformity, into a series of massive quartzose grits alternating with very finely-laminated shales, light to dark grey in colour, which are lettered (on the Survey map) as being of Lower Llandovery age. As one descends the sequence these grits gradually become less prominent, and the lowest beds in the district consist almost entirely of light-grey to bluish-black mudstones and shales.

The rocks are arranged, broadly speaking, in a long syncline, the axis of which runs almost due north and south (see fig. 7, p. 688). The central part of the Tarannon tableland is everywhere occupied by the Denbighshire strata, except along the valley of the Afon Cwm Calch, where they have been removed by denudation, and the underlying Tarannon Shales are exposed. The outcrops of the older beds follow that of the Denbighshire Group in successive and fairly-regular curves, the lowest beds of all being exposed in the valley of the Twymyn, which lies to the extreme west. The dip of all the beds older than the Denbighshire Group is high, varying from 40° to 60°, and their outcrops, especially on the west side, often make an almost straight line across both hills and valleys.

The large syncline has been subjected to considerable minor folding, due to lateral pressure coming apparently in the main from the north-west. The result of this movement has been to fold the rocks into repeated subsidiary anticlines and synclines, the axes of which cross that of the main axis obliquely and run in a north-north-east and south-south-west direction. Where the arenaceous beds predominate over the argillaceous, the strata have yielded in regular and symmetrical folds. Where, on the other hand, the strata are chiefly shaly, the rocks have suffered more violent deformation and have been bent into repeated sharp folds, which are almost isoclinal in their character, and are frequently broken and faulted to a considerable extent. In addition there is a north-and-south movement which has bent the rocks into broader waves, causing the folds to pitch in these two directions, but not producing any acute cross-folding. In the western and southern parts of the district the rocks are much cleaved.

Some idea of the number of the more important folds may be obtained by an examination of the 1-inch Geological-Survey map of the area lying to the north and east of the present district. On this the outcrops of the 'Tarannon' and so-called Llandovery Beds are shown extending north-eastward, in long narrow V's into the Denbighshire Series, each V marking the position of an anticlinal fold.

Practically the only fossils that I have obtained in this district are graptolites. In the upper and more gritty half of the succession these appear to be restricted to occasional bands, which are rarely more than a fraction of an inch in thickness. They are difficult of detection among the large mass of unfossiliferous strata, as the lithological character of the beds gives but little guidance. On the whole, however, it may be said that graptolites are most commonly met with in brilliant orange-weathering shales which immediately underlie small flaggy beds, and they are frequently found plastered on to the under side of the flags themselves. The graptolites found in some of the upper beds are generally preserved in low relief; but they are seldom seen in the normal profile view, and are therefore often difficult of identification.

In the lower part of the succession, where the beds are more generally shaly, graptolites are more abundant, and occur at frequent

horizons. Owing, however, to the deformation which the beds have undergone, they are, as a rule, difficult of extraction and poorly preserved, and are practically confined to the darker grey or black shale-bands.

II. Stratigraphical Relations of the Rocks in the Tarannon District.

(A) Description of the Typical Section in the Tarannon River.

The valley-course of the Tarannon River affords the longest, the most continuous, and, on the whole, the most satisfactory section in the district. It rises near Llyn Gloew in the centre of the Tarannon moors, and flows thence first southward across the central part of the tableland itself; then south-eastward down its flanks; and finally, eastward beyond the base of the tableland, to join the Severn at Caersws.

(1) **Wenlock Series (C).**

(i) Fynyddog Grits (Cb).

All the central part of this Tarannon tableland, over which the Tarannon River flows for the first 2 miles or more, is occupied by the Denbighshire Grits; but, owing to the boggy nature of the ground, the bed-rock is exposed at the surface only in isolated patches. Wherever rocks are seen, however, they consist of grey felspathic and micaceous grits varying in thickness from a few inches to several feet, separated by bluish-black mudstones, shales, and flags. Many of the beds show marked concretionary structure, and frequently weather to a brilliant orange colour. These strata, which are identical with those of the great sheet of Denbighshire Grits in the country to the north, may be termed the Fynyddog Grits, from the heights of Newydd Fynyddog.

They are well exposed in the river-course close to the farmstead of Tarannon, where they dip east-north-eastward at an angle of 23°, while fairly-massive grits are seen both in the river-bed and also protruding through the peaty ground on both sides for some distance down the stream. Judging from the form of the ground, we may infer that these Fynyddog Grits are continued as far as the sheep-fold, nearly 1 mile below the Tarannon farmstead, and in this part of the district they must have a thickness of at least 1500 feet. No search for fossils has yet been made in these beds.

(ii) Nant-ysgollon Shales (Ca). (Zone of *Cyrtograptus Murchisoni.*)

As we follow the river southward the grits disappear, and we find coming out from below a broad band of flaggy shales and mudstones

which we may term the Nant-ysgollon Shales, from a well-known locality at the north-eastern end of the moorland, where these beds are exceptionally well exhibited. They occupy some 350 yards of the river-course, and make their first appearance a few yards to the north of the Ford, where a small tributary stream joins the Tarannon River on its right bank. Here some dark bluish concretionary mudstones and shales, weathering in places to a reddish brown, yield excellent specimens of *Cyrtograptus Murchisoni*, Carr., and *Monograptus vomerinus*, Nich.

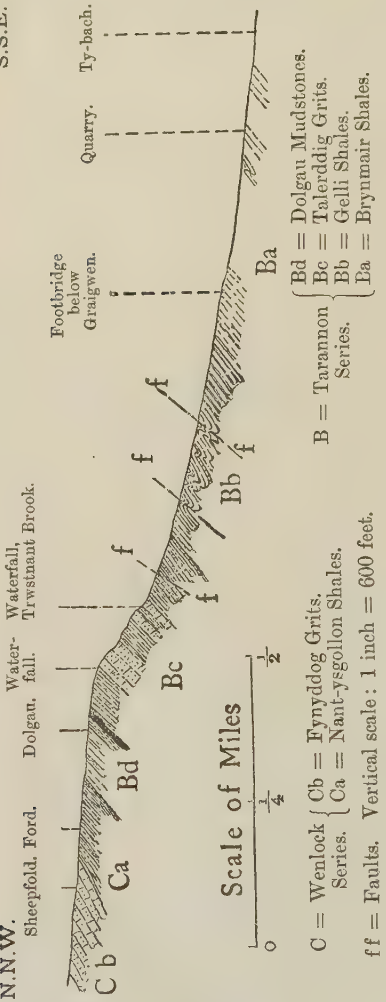


Fig. 1.—*Section along the Tarannon River.*

For the next 140 yards sandy flags and shales are exposed at various localities on the right bank of the river. Originally bluish in colour, these rocks weather deeply, and present a dirty greyish-brown or even ashen-grey appearance. They dip at an angle of 35° to 40° north-north-westward. Although no complete specimen of *Cyrtograptus Murchisoni* has been found in these lower beds, yet isolated branches occur which are almost certainly referable to this species, and they are associated with the following forms[1]:—

Retiolites Geinitzianus, Barr. (C).
Monograptus vomerinus (C).
Monograptus crenulatus, Törnq. (f. C).
Monograptus priodon, Bronn (f. C).
Monograptus riccartonensis, Lapw. (R).

It is difficult in this section, owing to the absence of sufficient exposures, to fix with exactitude the boundary between the Nant-ysgollon Shales (Ca) and the overlying Fynyddog Grits (Cb), but the thickness of the shales may be set down at about 450 feet.

[1] In this and succeeding lists of fossils, C = common; f. C = fairly common; R = rare; v.R = very rare.

The Fynyddog Grits and Nant-ysgollon Shales correspond to the bands of Denbighshire Grit and underlying Denbighshire Shale, as laid down on the Geological-Survey maps and coloured as Wenlock. The fossil-evidence here obtained definitely establishes their Wenlock age, for the fauna of the Nant-ysgollon Shales is that of the zone of *Cyrtograptus Murchisoni*, which is the basement-zone of the Wenlock elsewhere. Below the Nant-ysgollon Shales we enter upon the beds which belong to the Tarannon Series.

(2) Tarannon Series (B).

(i) Dolgau Mudstones (Bd). (Zone of *Monograptus crenulatus*.)

Beyond a distance of some 170 yards below the Ford the strata for 200 or 250 yards present distinctive lithological characters, which readily serve to separate them from the Nant-ysgollon Shales above. They consist, for the most part, of fine, smooth, greyish-green mudstones and shales, with occasional thin flaggy beds from about a quarter to $1\frac{1}{2}$ inches thick, which become more abundant as we descend the section. They dip steadily northwestward, at an angle of about 40°.

This group of strata graduates so insensibly from the Nant-ysgollon Shales above, that it is difficult to fix upon any definite boundary between them. In this Tarannon section, however, a convenient separating-line is formed by some few coarse greywacké-bands which give origin to a small waterfall. The Mudstone Group as a whole is divisible into three sub-groups.

Upper Green Mudstone Sub-group (Bd_3).—The beds of this highest sub-group consist of mudstones of a peculiarly-smooth and soapy texture, associated with a few thin flags. When fresh, these mudstones are of a pale greyish-green colour, but they weather to a dirty brown. The rocks occasionally show evidence of movement, and are in places slickensided and wrinkled, but the disturbance does not affect their general disposition. No trace of fossils has been detected in this sub-group.

Middle Purple Mudstone Sub-group (Bd_2).—The green mudstones give place to a second sub-group of strata, which differs (1) in the purple (or, to speak more accurately, deep maroon) colour of some of its beds; and (2) in containing more arenaceous material. This sub-group thus consists of alternations of green and purple beds. At the summit there are about 40 feet of purple mudstone practically unbroken by any green bands, and showing occasional thin grey flags which vary in thickness from a quarter to $1\frac{1}{2}$ inches, and become especially prominent near the base. The change in colour from green to purple is a gradual one, and the purple tint fades away imperceptibly into the green.

This band of purple mudstone is underlain in its turn by strata of a green colour having a thickness of 45 feet. Like the purple

band above they contain many flaggy layers. They pass downward gradually into 6 feet of purple shaly mudstones; and these again are underlain by 6 feet of greenish mudstones, having a prominent but thin flaggy bed at the base. All these purple and green strata are well exhibited in the high and steep banks on the east side of the river.

Below this thin band of green occurs 130 feet of soft purple mudstones and shales which form the base of this sub-group (Bd_2). As these lowest strata contain but few beds of flags, they are not conspicuous in either bank, although they may be seen in the stream when the water is low. They end at a point 20 to 30 yards below the footbridge opposite the farm of Dolgau. The total thickness of this Middle Sub-group, which, as we have seen, consists of three bands of purple and two of green, must therefore be about 225 feet; it appears to be quite barren of fossils.

Lower Green Mudstone Sub-group (Bd_1).—Below the lowest bed of purple mudstone a third sub-group of strata comes on, consisting of green shales and mudstones intercalated with numerous thin flags, and containing a few black carbonaceous bands at the base. This group has a total thickness of about 95 feet. The five black bands are shown below the footbridge, and occur within a distance of 18 yards. They all yield graptolites, but these are, as a rule, indifferently preserved. Collectively they contain the following species :—

Monograptus crenulatus (C).
Monograptus priodon (C).
Monograptus subconicus, Törnq. ? (f. C).
Monograptus discus, Törnq. (R).
Monograptus griestonensis, Nicol ?
Monograptus nudus, Lapw. ?
Retiolites Geinitzianus (f. C).

As these dark graptolite-bearing shales, which have a thickness of about 30 feet, are readily recognized and can be identified elsewhere, I regard them as forming the base of this Lower Green Mudstone Group.

We see, therefore, that immediately below the Nant-ysgollon Shales comes a group of strata some 420 feet thick, showing great mineralogical similarity throughout, but varying in colour from purple to green. It is made up of three divisions :—

	Feet.
Bd_3. Upper Green Mudstones, unfossiliferous	100
Bd_2. Middle Purple Mudstones, with some flaggy beds, unfossiliferous	225
Bd_1. Lower Green Mudstones, with numerous flaggy beds and containing graptolitic bands	95

Hitherto fossils have only been obtained in the lowest beds; four of the species are common to the Nant-ysgollon Shales above; but *Cyrtograptus Murchisoni*, the characteristic fossil of the Wenlock Shales, is absent. The remaining three species, *Monograptus griestonensis*, *M. discus*, *M. subconicus*, which are absent from the Nant-ysgollon Shales, are rare forms at this horizon, and are far more characteristic of the beds below.

This group of strata, which I have termed the Dolgau Mudstones, from the farmhouse of Dolgau at this locality, may be referred to under the alternative title of the local zone of *Monograptus crenulatus*, after its dominant fossil.

When we transfer on to our present 6-inch maps the upper and lower boundary-lines of the local Tarannon Shales, as laid down upon the geological maps of the Tarannon district by the officers of H.M. Geological Survey, at this their type-locality (see quarter-sheet 60 S.W., Montgomeryshire), we find that these coincide almost precisely with the top and bottom of our lithological group of the Dolgau Beds. Thus, in this part of the Tarannon district at all events, our Dolgau Beds and the 'Tarannon Shales' of the Survey are identical.

(ii) Talerddig Grits (Bc). (Zone of *Monograptus griestonensis.*)

Underneath the Dolgau Beds comes a group of strata which is perhaps the most conspicuous in the district, and to its peculiar lithological characteristics are due in a large measure the more marked scenic features of the Tarannon heights. This group may be fittingly termed the Talerddig Group, from the excellent development of its strata in the railway-cutting at Talerddig, at the north-eastern end of the area.

Unlike the Dolgau Mudstones, which, as we have seen, are essentially shaly, these Talerddig rocks are markedly arenaceous. They consist in the main of rapid alternations of thinly-bedded greywackés and shales, but there occur in addition numerous beds of thick grit. These mass themselves together at certain horizons, and form definite bands that stand out in marked contrast to the intervening bands of thinner flags and shales.

Thus the Talerddig Group is made up of alternations of what may be termed grit- and shale-bands. The 'grit-bands' contain numerous beds of grit with a variable but subordinate thickness of shaly material; the 'shale-bands' consist in the main of shales and thin flags, with only an occasional grit.

The quartzose grits vary in thickness from 6 inches to 6 feet, but only a few reach the latter size. They are for the most part grey in colour, and are indeed typical greywackés. The matrix varies considerably in texture, although it is usually fine-grained and the included fragments are rarely even of the size of a pea; and in no case observed do they approach in coarseness to that of an ordinary conglomerate. There is every gradation, both in texture and thickness, between these more massive beds and the intervening, fine-grained, micaceous flags, which may be only a fraction of an inch in width. Some of the greywacké flags exhibit cone-in-cone structure, and many show the trails of annelids impressed on their bedding-planes, the irregular hummocky and rippled upper surfaces of which suggest that shallow-water conditions prevailed at the time of their deposition.

The interbedded shales are usually well laminated, and of a very fine smooth texture. They are light to dark grey and even black,

and frequently weather to a bright yellow or orange tint. It is in these brilliantly-coloured bands that graptolites are most commonly found.

Like the Dolgau Beds, the Talerddig Grits and Shales strike 40° to 50° east of north, and dip north-westward at angles varying from 45° to 55°. As exposed in the Tarannon River, they are capable of division into the following lithological bands :—

	Thickness in feet.
11. 6th shale-band	175
10. 5th grit-band, 9. 5th shale-band	310
8. 4th grit-band	35
7. 4th shale-band	35
6. 3rd grit-band	30
5. 3rd shale-band, 4. 2nd grit-band, 3. 2nd shale-band	170
2. 1st grit-band	70
1. 1st shale-band	325
Total	1150

Unfortunately, the section is not quite complete either in the bed of the river or on the banks, and therefore the exact thickness and character of some of the bands are somewhat uncertain.

The uppermost member of this Talerddig Group is a shaly one, and differs at first but little in lithological character from the Dolgau Beds above, although the small greywacké-flags have become more numerous and individually thicker, while the pale-green colour so characteristic of the Dolgau Beds has given place gradually to a light-grey tint. No trace of a fossil has yet been detected in this band.

This 6th shale-band is underlain by the 5th and highest grit-band, the first grit of which is exposed in the bed of the river, below the small waterfall south of Dolgau Farm. At first the grits are of no great thickness, and are interbedded with numerous shales and flags; but, as we descend the sequence, they come on in full force immediately to the south of a small stream on the left bank, and give origin to small waterfalls in the bed of the main river. This 5th grit-band is the most important, both in collective thickness and in the size of the individual beds of grit; and it always makes a conspicuous feature along the hill-sides wherever it occurs. It contains at least twelve beds of grit of 2 feet and upward in thickness, and a few of from 4 to 6 feet (if we disregard thin shale-partings). From one of the thin shale-bands between the two highest beds of grit the following species of graptolites were obtained :—

Monograptus griestonensis (C).
Monograptus subconicus (C).
Monograptus priodon (f. C).
Monograptus discus (f. C).
Monograptus nudus (f. C).
Monograptus crenulatus (R).
Monograptus cf. *dextrorsus*, Linnrs. (R).

The 5th shale-band below is not well exposed, and its limits cannot be accurately defined; but the presence of softer shales,

rather than of grits, may be inferred from the more gentle fall of the river-bed and from the absence of good rock-exposures. No search for graptolites was made in these shaly bands, but doubtless they are to be found at certain horizons.

This softer shale-band is underlain by more gritty strata, constituting a thin but well-marked grit-band (4th) of some 35 feet, and forming the top of the largest waterfall in the upper course of the Tarannon River.

Beneath this comes the 4th shale-band, which forms the floor of the waterfall, and is of about the same thickness. It contains a few darker grey or black shale-layers, from which the following graptolites were identified:—

Monograptus priodon (C).	*Monograptus subconicus* (C).
Monograptus griestonensis (C).	*Monograptus Marri*, Perner (C).
Monograptus discus (C).	*Monograptus nudus* (C).

The bottom of the waterfall is constituted by the 3rd grit-band, which is similar in thickness and character to the one overlying it. At the foot of this waterfall the Trwstnant stream joins the main river on its right bank. This stream, in the lower part of its course, has cut a deep and narrow gorge along the strike of the beds belonging to the 3rd grit-band. A good fossiliferous locality was detected in the northern bank about 2 feet above the topmost grit-bed, and from a thin shale-layer all the graptolites mentioned above were collected.

For a distance of about 60 yards below the waterfall the beds are only exposed incompletely in the left bank. The 3rd grit-band, however, is seen to be underlain by a more shaly group (3rd shale-band), while below this again the occurrence of occasional grits from 1 to 2 feet thick clearly indicates the presence of a 2nd grit-band, though its extent and detailed character are here indefinite.

The 2nd shale-band intervenes between this and a first and lowest grit-band, which is well shown at the point where the river makes a sharp bend to the north-east, almost at right angles to its previous course. This 1st grit-band contains several grits of 1 and 2 feet in thickness, but there is, on the whole, a greater proportion of shales than in the overlying grit-bands. Two normal faults cut the strata at this point and throw the beds down to the west, but do not displace them more than 10 and 20 feet respectively. It is possible that similar faults may affect the beds belonging to the 2nd shale-band above; but they have not been detected, owing to the fact that the rocks are to a great extent obscured by vegetation.

The lowest important assemblage of grits is underlain by the 1st shale-band, which is of considerable thickness and contains six grits of about 8 to 14 inches near its centre. Some 40 feet below these grits, at a point where the river makes another sharp bend to the east, a thin dark shale-layer and an overlying bed of greywacké yield most of the species of graptolites which have yet been detected in the upper beds of the Talerddig Group, namely:—

Monograptus priodon (C).	*Monograptus nudus* (C).
Monograptus griestonensis (f. C).	*Monograptus subconicus* (f. C).
Monograptus Marri (C).	*Monograptus discus* (f. C).

Some 120 feet below this graptolitic locality, a single grit-bed 14 inches thick is exposed, and in the intervening shaly strata similar well-preserved graptolites were found. This 14-inch grit is almost the last seen in the Tarannon section, and it may conveniently be regarded as forming the base of the Talerddig Grits.

Reviewing the Talerddig Group as a whole, we see that it consists of alternations of grits, greywackés, and shales, having perhaps a collective thickness of 1100 to 1150 feet. The arenaceous beds are, as a rule, only a few inches thick; but at five distinct horizons they increase to between 1 and 4 feet in thickness, and are more or less massed together to form compound grit-bands.

The fauna of the Talerddig Group is similar throughout, and while it is distinct as a whole it is intimately related to that of the Dolgau Beds above. Eight species have been detected, of which all but one (*M. Marri*) range up into the overlying group. *Monograptus crenulatus*, however, which is abundant in the Dolgau Beds, makes its appearance only in the highest fossiliferous seam of the Talerddig Group; while *M. griestonensis*, *M. discus*, *M. nudus*, and *M. subconicus*, which are doubtfully or poorly represented in the Dolgau Shale, are at their maximum development in the underlying Talerddig Grits. The most characteristic and abundant species is undoubtedly *M. griestonensis*, and the Talerddig Group may therefore be referred to under the alternative title of the *Monograptus-griestonensis* Beds.

As we have already seen, the officers of H.M. Geological Survey regarded the strata immediately underlying their Tarannon (Dolgau) Shale of this special section as of Lower Llandovery age, and distinguished on the map two bands—an upper shaly and a lower gritty one. Their Lower Llandovery Beds include the upper half of our Talerddig Group: their upper shale-division answering to our 6th shale-band, and their lower grit-division to the beds between the 5th and 3rd grit-bands. Both on lithological and palæontological grounds, however, the base of the Talerddig Group should be carried down to the lower horizon which we have chosen.

So long as the beds referred to were regarded as of Lower Llandovery age, a stratigraphical break presumably existed between the Talerddig and Dolgau (Tarannon) Beds. But all the evidence—lithological, stratigraphical, and palæontological—now obtained goes to show that there is a complete gradation between the two.

(iii) Gelli Shales (Bb). (Zone of *Monograptus crispus*.)

The Talerddig Beds pass down with complete conformity into a thick group of strata, which lithologically differ from them mainly in the absence of the grit-bands. They consist of alternations of well-laminated, light-grey, blue, and black shales with occasional mudstones and small micaceous flags (a quarter to 2 inches thick), the latter decreasing in number and thickness as one descends the section.

This group of beds may be termed the Gelli Shales, from the farms of Gelli-dywyll and Gelli along the western flanks of the tableland, near which the shales are well-developed.

Unlike the groups which we have described down to this point, wherein the descending sequence is practically unbroken by faults and folds, the rocks of this Gelli Group have been much disturbed. They have been subjected to earth-crust movement from the north-north-west, resulting in the frequent repetition of many of the beds by means of sharp folds. These folds are probably of small amplitude, but their crests, which are shown at intervals in the high banks of the river, are very sharp, and are sometimes accompanied by faults, so that the steady north-westerly dip of the beds is only interrupted occasionally and that for a distance of a few yards.

These folds in their course to the north-east cut across the continuation of the Talerddig Beds, and are well shown on the 1-inch Geological-Survey map by the zigzag shape of the outcrops on the hill above and to the east of the river. This folding prevents us from making more than a rough estimate of the thickness of the Gelli Shales; but it cannot be less than 800 to 1000 feet, and may be more.

Coming now to the details of the section, so far as it is exposed in the Tarannon River, we find that underneath the lowest grit-band of the Talerddig Group there is a thickness of about 150 feet of grey shales, alternating every few inches with numerous thin flags. Fossils are rare in these beds, but specimens of *Monograptus Marri* and *M. nudus* were obtained. Below these shales some blue-black flaggy beds, exposed along their strike where the river curves abruptly to the north-east, yield examples of *M. Marri* in great abundance, together with *M. nudus* and *M. subconicus (?)*. At this point the left bank of the river is very lofty, and presents a magnificent section of Gelli strata. Here and there an occasional softer and darker band of shale, often only a fraction of an inch in thickness, and generally weathering to a brilliant orange colour, yields graptolites; and from one of these seams, at a point about 300 feet below the base of the Talerddig Group, there were obtained:—

Monograptus crispus, Lapw. (f. C).
Monograptus exiguus, Nich. (f. C).
Monograptus Marri (f. C).
Monograptus discus (f. C).
Monograptus nudus (f. C).
Monograptus subconicus (f. C).
Petalograptus palmeus, var. *tenuis*, Barr. (C).
Monograptus priodon.

Immediately beyond this seam the beds become vertical, and are bent over into a sharp fold, the southern limb of which is partly replaced by a fault. The beds right themselves, however, within a few yards, and return to their normal dip of 45° north-westward.

Continuing the section, we find that the beds vary but little in lithological character, although the flaggy seams decrease in number and thickness. They dip generally north-westward, but every now and again are crumpled and folded to a greater or less extent.

Graptolites were obtained at various localities, the species being the same as those cited above.

A few yards below the point where a small stream enters the river on the left bank, two well-marked grits, of 16 inches and 2 feet in thickness respectively, are seen; and, in a thin dark shale-band above them, the following graptolites were found in abundance and in a fair state of preservation :—

Monograptus crispus (C).
Monograptus priodon (C).
Monograptus nudus (f. C).
Monograptus discus (R).
Monograptus turriculatus (v. R).

These grits are of some stratigraphical importance, as they may be recognized at other localities and mark a definite horizon in the Gelli Group.

Descending the river for about 80 yards, one may see another fold well exhibited in the left bank. The beds are much contorted, and are penetrated by quartz-veins in all directions, while the shales below the fold are cleaved. The strike of the cleavage coincides with that of the beds, and is about 50° east of north; while its dip is about 20° higher than that of the beds, which is 35°.

The last locality at which *Monograptus crispus* and its associates were obtained in this Tarannon-River section is 140 to 150 yards below this fold, and almost due east of the farm of Graigwen. The beds here consist of dark-grey banded mudstones, which weather to an orange tint. The base of the Gelli Group is drawn provisionally a short distance to the south of this locality, at a point some 150 yards above the footbridge south of Graigwen: because below this point we find that there is a gradual but distinct change, both in the lithology and in the fauna of the deposits.

Reviewing the graptolitic fauna of the Gelli Group, we find that it contains eight species, of which five are common to the Talerddig Beds above. *M. crispus* is, so far as known, restricted to these Gelli Beds, and is characteristic of them, not only in this section but elsewhere in the district. The Gelli Group may, therefore, be referred to as the *Monograptus-crispus* Beds. *M. discus* and *M. subconicus* occur both in the Gelli and in the Talerddig Groups, but are distinctly less abundant in the lower beds. *M. exiguus*, *M. turriculatus*, and *Petalograptus palmeus* var. *tenuis*, which occur in the Gelli Beds, are unknown in the Talerddig Grits above, but pass down into the Brynmair Shales below. Of these graptolites, however, *M. turriculatus* is extremely rare, only one specimen having been found.

(iv) Brynmair Shales and Mudstones (Ba).
(Zone of *Monograptus turriculatus*.)

Below the Gelli Shales we enter upon a new group of strata, that is, on the whole, distinctly less sandy, and consists almost entirely of soft shales and mudstones, which have consequently suffered to a considerable extent from the effects of folding and cleavage. While the exact order and limits of these beds cannot be fixed, yet a

sufficient extent is shown in the Tarannon River along this line of section to enable us to see that this group is as important as any of the divisions already noticed, and its collective fauna distinct from that of the overlying Gelli Shales. This group is termed the Brynmair Beds, from the village of Llanbrynmair in the valley of the Twymyn, where their relations to the overlying and underlying strata are well shown.

The highest horizon at which graptolites were obtained is a few yards below the footbridge already mentioned. Here the beds consist of thin shales and small flags, and yield:—

Monograptus runcinatus, Lapw. (C).	*Monograptus turriculatus*.
Monograptus densus, Perner (f. C).	*Petalograptus palmeus*, var. *tenuis* (C).

On the left bank, south of the bridge, in the scree-slopes, which are here of great height, many specimens of *M. runcinatus* were obtained.

Below the footbridge the river-valley is somewhat more open, and the high banks have receded some distance on the east side; but fairly-continuous exposures may be obtained, either in the bed of the river, or along the road running parallel to it. At one locality along this road, north of Allt-Goch Cottage and about 10 yards south of a place where the beds are extremely disturbed, *M. runcinatus* (C), *M. turriculatus* (f. C), and *M. Halli*, Barr. (?), were obtained from a thin flaggy band which had to some extent resisted the cleavage.

In a small quarry on the left of the road, some yards still farther south, there is a good exposure of compact blue mudstones; and similar rocks may be seen at other localities lower down the road, the dip in every case appearing to be north-westerly.

No graptolites were obtained from these Lower Brynmair Beds on the east side of the river; but on the west, along a road some 200 feet above the river and opposite Ty-bach, there occurs a fairly-rich fauna of graptolites in some finely-banded grey shales, stained on the surface to a dull purplish colour and weathering deeply to an ashen-grey tint. The species which could be identified include:—

Rastrites Linnæi, Barr. (R).	*Monograptus nudus* (f. C).
Monograptus turriculatus (R).	*Petalograptus palmeus*, var. *tenuis* (f. C).
Monograptus densus? (R).	*Climacograptus* sp.
Monograptus cf. *proteus*, Barr. (C).	

This is the last locality examined in the Tarannon Valley; but similar beds continue for a long distance to the south-east. These are, however, so folded, contorted, and cleaved, that the section is comparatively valueless from the stratigraphical point of view. Fortunately, the deficiency is compensated for in the western part of the district.

The fauna of the Brynmair Group, as here determined, consists of eight species, of which three only are found in the overlying Gelli Group. The first species of *Rastrites* met with in the descending succession occurs in these beds. Perhaps the most characteristic form is *Monograptus turriculatus*, and the Brynmair Group may, therefore, be fittingly termed the *Monograptus-turriculatus* Beds.

It is evident, from the foregoing description of this typical Tarannon section, that it exhibits a collective thickness of about 5500 feet of strata, which may be grouped as follows:—

			Feet.
Wenlock Series.	Cb. Fynyddog Grits		1500
	Ca. Nant-ysgollon Shales (Zone of *Cyrtograptus Murchisoni.*)		450
Tarannon Series.	Bd. Dolgau Mudstones. (Zone of *Monograptus crenulatus.*)		
	Bd_3. Upper Green Mudstones	100	420
	Bd_2. Middle Purple Mudstones	225	
	Bd_1. Lower Green Mudstones	95	
	Bc. Talerddig Grits. (Zone of *Monograptus griestonensis*)		1150
	Bb. Gelli Shales. (Zone of *Monograptus crispus*)		900 (?)
	Ba. Brynmair Shales. (Zone of *Monograptus turriculatus*)		1000 (?)

From the top of the Fynyddog Grits to the lowest beds described in the Tarannon section, there is an unbroken descending sequence of strata possessing a general community of lithological characters; and the graptolitic fauna of the beds, although presenting, as one descends the sequence, gradual changes due to the disappearance of some forms and the coming-in of others, might, like the rock-series, be regarded to some extent as a unit.

But, on palæontological grounds, the Fynyddog Grits and the underlying Nant-ysgollon Shales, which contain *Cyrtograptus Murchisoni*, must be grouped with the Wenlock Series, of which the zone of *C. Murchisoni* is universally regarded as the basement-zone.

The collective fauna of the rock-series composed of the four underlying groups—which, from its grand development in this section, we term the Tarannon Series—is distinct as a whole from that of the Wenlock. It is divisible into four local zones, namely, those of *Monograptus crenulatus*, *M. griestonensis*, *M. crispus*, and *M. turriculatus*. The graptolitic faunas of these four zones are quite distinct from those usually classed as Llandovery.

(B) Confirmatory Sections.

(1) Northern Area.

(i) Afon Iaen and Talerddig to Llanbrynmair Road-and-Railway Section.

Turning now to the northern end of the Tarannon district, we find an excellent confirmatory section exhibited, partly in the bed of the Afon Iaen, and partly in the main road and railway from Talerddig to Llanbrynmair Station which run parallel to this stream. The section passes in a general north-westerly direction across the northern end of the Tarannon promontory, showing well the synclinal form of the country, and affording a more or less continuous section from near the top of the Nant-ysgollon Shales to the base of the Gelli Group. (See Pl. XLVIII, fig. 1.)

Talerddig Group (Bc).—For a distance of about a quarter of a mile to the north and south of the village of Talerddig we find everywhere evidences of the presence of the Talerddig Group. The strata dip in a general north-westerly direction, and disappear below the overlying Dolgau Beds between Dolgoch and Pandy-bach. The most complete section of the Talerddig Beds in this part of the district is that exposed in the railway-cutting north of Talerddig siding. Here the beds, which dip at angles of 42° to 48° north-westward, consist of alternations of grit- and shale-bands, similar on the whole to those exposed along the Tarannon River, but differing somewhat in the details of their lithology and thickness. They are divisible into the following rock-bands, arranged in descending order:—

		Thickness in feet.
9. Shale-band (*e*)		60 to 70 (incomplete).
8. Grit-band (*d*).		
i. Grits	12	113
ii. Shales	14	
iii. Grits	55	
iv. Shales	8	
v. Grits	24	
7. Shale-band (*d*)		35
6. Grit-band (*c*)		40
5. Shale-band (*c*)		36
4. Grit-band (*b*)		33
3. Shale-band (*b*)		60
2. Grit-band (*a*)		30
1. Shale-band (*a*)		40 (incomplete).

The lowest beds exposed in the railway-cutting consist of shales and thin flags; their base is not seen, for the rocks are here obscured by vegetation. The first grit-band (*a*) shown includes among others a grit of about 4 feet in thickness. Evidences of disturbance of the strata are apparent on the eastern side of the cutting, where one of the grits is seen to be twisted and fractured. The grit-bands (*b*) and (*c*) agree closely in character and thickness with the 3rd and 4th grit-bands in the Tarannon section. Where they crop out at the surface on the eastern side, they form projecting cornices, while the intervening shales occupy a deep recess. Some of the grits which belong to grit-band (*b*) are also well shown in a small quarry, some 50 or 60 yards to the east of the railway.

A few graptolites were found in the shale-band intervening between the grit-bands (*c*) and (*d*). They include the following typical Talerddig species:—

Monograptus priodon.
Monograptus griestonensis.
Monograptus subconicus.
Monograptus discus.
Monograptus nudus.

The highest grit-band met with answers apparently to the 5th in the Tarannon section, and, like that, is the thickest. It contains several strong grits, and forms a prominent feature on the western side of the cutting just below the railway-bridge.

This grit-band is overlain by a shale-band, of which more than

60 feet is exposed before the section is interrupted. Between this point and Dolgoch the beds are only shown occasionally, and are bent into a series of gentle folds. In some cases the axes of these folds are well exhibited, the most striking perhaps being that on the west side of the railway-line slightly north of Dolgoch, which figures in all the local guide-books as the 'Natural Arch.' It is even more clearly seen along the road on the east side of the railway, and consists of fairly-thick grits with alternating shales. Beyond the 'Natural Arch' there are evidences of other smaller undulations along the roadside, until eventually the beds once more resume their normal north-westerly direction, and the Talerddig Grits pass up into the Dolgau Mudstones. The passage between these is best shown in the bed of the Afon Iaen. This river is confined within an artificial conduit for a distance of 145 yards near the 'Natural Arch'; but, from the point where it emerges, a continuous section can be studied for a long distance down its valley-course. The first beds are the characteristic shales and greywackés of the highest shale-band of the Talerddig Group. They were examined carefully for graptolites, but without much success, for these do not appear to be confined to such definite layers as usual. *Monograptus priodon*, *M. subconicus*, *M. nudus*, and *M. griestonensis* were found at a point about 50 yards from the commencement of the section. The thickness of this shale-band (*e*), of which only a part is exposed in the railway-cutting, must here be about 250 feet; while that of the whole Talerddig Group cannot be less than 700 feet, and the true base is not visible.

Dolgau Beds (Bd): Lower Green Mudstones (Bd_1).—As we descend the stream, the lithological character of the beds is seen to undergo a change. The rocks become lighter in colour, less arenaceous, and more of the nature of mudstones, and they lack the brilliant weather-colouring of the Talerddig Shales. They resemble the lowest Dolgau Mudstones seen in the Tarannon section, and like those have black shale-bands at their base containing graptolites. At this locality these soft black shales are so slickensided and disturbed (owing probably to a small fault) that the fossils are almost unrecognizable; but from one of the lowest bands *Monograptus priodon*, *M. subconicus*, and *M.* cf. *dextrorsus* were identified.

The highest black band is seen on the right bank, about 17 yards north of the hedge which comes down to the river. It is barely an inch thick, but has yielded a fairly-rich assemblage of species, including :—

Retiolites Geinitzianus (f. C).
Monograptus subconicus (C).
Monograptus griestonensis (f. C).
Monograptus priodon.
Monograptus nudus (f. C).
Monograptus Marri (f. C).
Monograptus discus (R).
Monograptus crenulatus (?).

Comparing this fauna with that of the black bands at the base of the Dolgau Group in the Tarannon section, we find a fairly-close resemblance between the two, the main difference being that the zone-fossil, *M. crenulatus*, is here doubtfully represented. At other

localities, however, in this northern area this species is common at the same horizon, and therefore its rarity here may be accidental. This highest black band is overlain by 40 feet of typical pale-green mudstones, with occasional thin flags, and the collective fauna of the Lower Green Mudstone Sub-group in this section must be about 90 feet.

Middle Purple Mudstones (Bd_2).—The overlying Purple Mudstone Group is well exhibited in the bed of the Afon Iaen, the strata here striking 60° east of north, and dipping at 35° north-westward. It consists of the following divisions, in ascending order:—(1) 40 feet of purple mudstones, with one or two thin green flaggy beds near the top; (2) 1 foot of green mudstones; (3) 18 inches of purple beds; (4) 5 to 6 feet of green, (5) 12 feet of purple, (6) 8 to 10 feet of green, and (7) 15 feet of purple mudstones; making a total thickness of about 85 feet. The thicknesses of the individual bands must be regarded as merely approximate, as the bed of the stream is not accessible at this locality. The highest of the purple bands extends to and slightly beyond the small footbridge, and is overlain by the typical Upper Green Mudstones.

This Purple Sub-group is fairly well exhibited also along the roadside a few yards to the east of the river, and in the small streamcourse above the road at Pandy-bach; but the thicknesses of the individual purple and green bands are not the same as in the river-section.

Upper Green Mudstone Sub-group (Bd_3).—Returning to the section in the Afon Iaen, we find that the Upper Green Mudstones succeed the Purple Sub-group, and can be followed along their dip for some distance, the angle of inclination varying from 35° to 42° north-westward. These strata present the same characters, of compact mudstones with rare flaggy beds, as those which distinguish this sub-group in the Tarannon section.

These beds are particularly well exhibited along the western side of the railway-bank just above the Iaen, at Pandy-bach. Unlike the corresponding beds in the Tarannon section, the Upper Green Mudstones have yielded fossils. These occur in two black shale-bands on the west side of the railway, which dip at 42° north-north-westward. The upper seam, which is the thicker, contains *Retiolites Geinitzianus* (C), *M. priodon*, and *M. crenulatus* (f. C). Some 30 yards above these black bands the beds are disturbed and penetrated by quartz-veins, black shales being involved in the fold at the foot of the bank; while a few yards farther north two dark bands, also about 4 feet apart, are well shown high up in the bank. These black graptolitic seams are apparently terminated abruptly on the south by a small fault; and there can be little doubt that they are identical with the two just described, having been brought up again to the surface by an anticlinal fold and fault combined.

Compact green mudstones continue to the extreme end of the

railway-section above Pont Pant-glas, where the axis of a synclinal fold is exhibited both on the eastern and western banks, the beds dipping at angles of 15° to 20° north-eastward. A thickness of about 2 feet of black shales is exposed in the centre of this fold on the west side, and this band is probably identical with that which, as we shall see later, marks the summit of the Dolgau Group. If this be so, then the thickness of these Upper Green Mudstones must average between 250 and 300 feet, while that of the whole Dolgau Group is 420 to 470 feet, figures which agree closely with those recorded in the Tarannon-River section.

The bed of the Iaen, from the railway-bridge to beyond Llawr-y-coed—a distance of one-third of a mile—, is occupied by various members of the Upper and Middle Dolgau Beds, their repetition being due to sharp folds of no great depth. The section has been worked on the 25-inch scale, but it need not be described here in detail.

Between Pont Bell and Plas-bach the Middle Purple Sub-group is brought up to the surface by an anticlinal fold, the purple bands being here much in excess of the green ones. On the west side of the fold the beds are snapped by a few small faults of very slight throw, but the eastern limb near Pont Bell has suffered to a greater extent. Careful examination shows that some of the upper beds are cut out altogether, and the junction between the Purple Sub-group (Bd_2) and the Upper Green Sub-group (Bd_3) is probably marked by a reversed fault.

A syncline brings up the Upper Green Mudstones immediately to the west of Plas-bach, while the Purple Beds are well shown at the Ford and opposite Glandwr. Near Factory Llawr-y-coed some compact green mudstones, the dip of which is obscure, are seen in the bed and left bank of the river; but along the footpath above they dip at an angle of 10° southward, and the axis of a fold, marked by the presence of quartz-veins, is indicated. The Purple Beds are again fairly well-developed in the bed of the river just above Llawr-y-coed, and pass up gradually into the Upper Green Mudstones, while these in their turn are immediately overlain by the Nant-ysgollon Shales. The transition between the Dolgau and Nant-ysgollon Beds is best exhibited along the north side of the road, some 300 yards to the west of Llawr-y-coed, in a high bank, which shows good exposures for nearly 200 yards. There is here, however, no trace of the grit-bands which form so convenient a division-line in the Tarannon-River section; but at about the same horizon there occurs a purplish-black band some 2 feet thick, which is particularly carbonaceous at its base. In this lower part graptolites are abundant, although they are in a poor state of preservation; it is nevertheless possible to identify the following species:—

Monograptus crenulatus (C).
Monograptus priodon (C).
Monograptus speciosus, Tullb. (f. C).
Monograptus (Cyrtograptus) spiralis, Tullb. (f. C).
Monograptus nudus (R).
Monograptus Linnarssoni, Tullb.
Retiolites Geinitzianus (f. C).

Of these forms the first four occur also in the lowest part of the Dolgau Beds, but three new species here make their appearance in addition. The fauna, however, on the whole is of the Tarannon type, as distinct from that of the *C.-Murchisoni* zone, and this band is therefore included at the top of the Dolgau Group.

Nant-ysgollon Shales (Ca).—The beds immediately overlying this black band are at first similar in lithological characters to those below; but as one ascends the sequence along the road they are seen gradually to pass into the bluish-brown concretionary shales and mudstones which are so typical of the Nant-ysgollon Shales of the Tarannon section, and indeed of the Wenlock Series throughout Wales. At one locality along the road, immediately to the east of the point where the bank is walled in, the characteristic Nant-ysgollon (Wenlock) graptolites were found in abundance and in a good state of preservation, including:—*Monograptus vomerinus* (v. C), *M. crenulatus*, *M. priodon*, *Retiolites Geinitzianus*, and *Cyrtograptus Lapworthi* (R) (= *C. Murchisoni?*). A thickness of at least 200 feet of the Nant-ysgollon Shales is exposed along this section, but the highest beds have been removed by denudation.

We have here reached the centre of the main synclinal axis of the country, and now begin to descend the sequence. The Nant ysgollon Shales continue for some distance in minor undulations, which are clearly visible in the bed of the Afon Iaen.

Dolgau Mudstones (Bd).—At a point, however, at the western end of a small coppice, due south of Cae-twpa Farm, the Dolgau Beds rise out from below the Nant-ysgollon Shales and the black band at their summit is exposed in the southern bank. For the next 300 yards the bed of the Iaen is occupied by the various members of this Dolgau Group, and they present the lithological characters that are typical of these beds elsewhere. The Middle Purple division, however, is poorly represented, and consists of a single band of purple mudstone, 8 feet thick, which is seen near Vaenol. Some of the black graptolitic bands at the base of the Dolgau Group are exposed 50 or 60 yards below Vaenol, but no fossils were obtained from them at this locality.

A small thickness of the highest shale-band of the Talerddig Group is brought to the surface between this point and Pont Dolfach by an anticlinal fold, the eastern limb of which appears to be partly replaced by a fault. Farther west, however, the Dolgau Beds once more make their appearance, owing to the presence of a shallow syncline, and occupy some 200 yards of the river-bed between Dolfach and the bridge below Pen-y-graig. In the centre of this trough a few feet of purple beds are shown, and on both the eastern and western sides the basement graptolitic beds of the Dolgau Group are seen resting upon the Upper Talerddig Shales.

On the west side the Lower Dolgau Mudstones reach their best development in this part of the district, and show at least ten well-

marked black bands, all of which yield graptolites in relief. They include:—

Monograptus priodon (C).	*Monograptus nudus* (R).
Monograptus crenulatus (f. C).	*Monograptus discus* (R).
Monograptus subconicus (C).	*Retiolites Geinitzianus* (f. C).

This fauna agrees closely with that from the corresponding beds in the Tarannon section and elsewhere.

Talerddig Group (Bc).—The Dolgau Beds pass down with complete conformity into the upper members of the Talerddig Group, which possess their usual characters. The river, however, for the next mile or so runs through an alluvial flat, and only occasional rock-exposures are met with. From these, nevertheless, it is clear that the country for the next half-mile, at any rate, is occupied by the Talerddig Grits bent into gentle folds, similar to those observed in the south-eastern part of this section.

Gelli Group (Bb).—At a point due south of Llwyn-ffynon there is an exposure of bluish-black mudstones, shales, and small flags which are much disturbed. Their lithological characters suggest that they belong to a lower horizon than that of the Talerddig Group, and some yards lower down the river, just below Pen-y-geulan, the following characteristic Gelli graptolites were obtained:—

Monograptus crispus (C).	*Monograptus priodon.*
Monograptus discus (f. C).	*Monograptus nudus (?).*
Monograptus Marri.	

The beds here, and for the remainder of the section, consist of thickly-bedded, deep, bluish-black mudstones weathering into spheroids, separated by very thin sandy shale-partings from which the graptolites were obtained. In this western area, therefore, the Gelli Beds present lithological characters very different from those exhibited in the Tarannon River, but the faunas at the two localities are identical.

Characteristic Gelli graptolites were also obtained from two bands in the Rhiw-saeson, just below Wynnstay Bridge, 400 yards from the junction of that stream and the Iaen; and the Gelli Beds are probably continued westward as far as Tafolwern, where they are cut off abruptly against another line of disturbance, marked by a large vein of quartz and much crumpling of the strata. No fossils could be detected in the beds lying immediately to the westward and the examination of the section was not continued; but, from evidence obtained elsewhere, it is fairly certain that they belong to the Brynmair Group.

Summing up the result of our examination of the Afon-Iaen section, we find that, in this northern area, it is possible to recognize the same groups of strata, arranged in the same order, as that worked out

in the Tarannon Valley from the Nant-ysgollon Shales to the base of the Gelli Beds. As the Afon Iaen cuts across the main synclinal axis of the country we pass twice over the complete sequence, while some of the groups of strata are repeated oftener by smaller local folds. The palæontological characters presented by the various groups in the two areas are practically identical, and the lithology and thickness agree fairly closely. On the whole, however, the beds in this northern area are more argillaceous than in the south. The Gelli Beds here consist mainly of shales and mudstones, while the grit-beds in the Talerddig Group are thinner and less numerous.

The Dolgau Beds retain their usual characters, but there is a greater preponderance of green rocks, and the purple bands, which, as we have seen, had a collective thickness of 175 feet in the Tarannon section, have decreased to 70 feet at the eastern, and even to 8 feet at the western end of the Afon-Iaen section. At the same time, however, the green bands which are interbedded with them appear to increase in corresponding proportion, so that the Dolgau Group, as a whole, does not show much diminution in thickness. At first sight, it appeared possible that there might be but one band of purple mudstone, which had been repeated by sharp isoclinal folding; but mapping on the 25-inch scale proved beyond doubt that there was no evidence for such intense folding, and that the simplest interpretation of the facts is that given above.

The variable character of its purple bands necessarily makes the threefold division of the Dolgau Group adopted in this paper a somewhat arbitrary one; but the Middle Purple Sub-group is so marked a feature over so large a part of the area that it can hardly be disregarded altogether. Moreover, the base of the Purple Group is on approximately the same horizon throughout the district.

(ii) Section in the Railway-Cutting north of Llawr-y-coed. (See fig. 2, p. 672.)

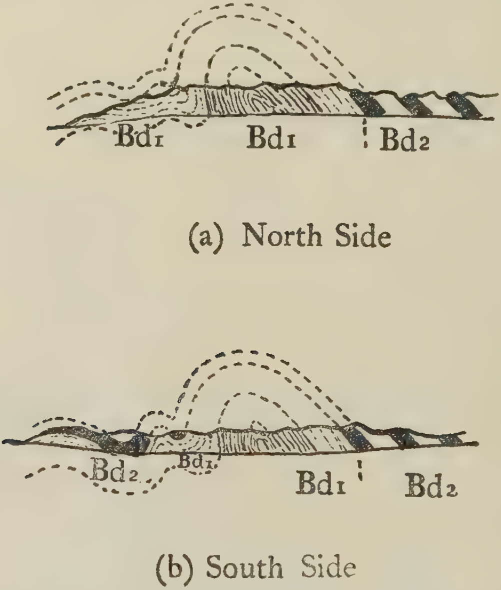
In this northern area there occur a few supplementary sections, which fall to be mentioned in this place. One of these is exhibited in the railway-cutting, east of the bridge due north of Llawr-y-coed, for a distance of about 170 yards.

The northern bank of the cutting is here 20 to 30 feet high, and presents us with a good section of the Dolgau Beds. Immediately to the east of the bridge the Middle Purple division is shown, the beds striking 10° west of north, and dipping at 40° to 45° west-south-westward. There are three purple bands, respectively 11, 9, and 15 feet thick, separated by two green bands of 21 and 15 feet respectively. The lowest purple band is underlain by 36 feet of green shales and mudstones with prominent flags, which pass down into the basement-beds of the Dolgau Group containing the usual black shale-bands. A few fragments of graptolites were got from these shales, identical with those obtained from similar beds at Pen-y-graig and elsewhere.

The Lower Dolgau Beds are bent into a sharp fold, which is

exceptionally well shown. It pitches to the southward, and is overturned towards the east. The Lower Dolgau Shales are repeated on the east of this fold and continue to the end of the section, where they are folded once more. In this cutting we have an index of the type of folding which is prevalent throughout the district.

Fig. 2.—*Section in the railway-cutting due north of Llawr-y-coed, on the scale of 25 inches to the mile.*



Bd_2 = Middle Purple Sub-group of the Dolgau Beds.
Bd_1 = Lower Green Sub-group of the Dolgau Beds, with graptolitic bands at the base.

The section in the southern bank of the cutting, although not quite so clear, presents some differences. As far as 97 paces from the bridge the beds exposed agree in all particulars with those in the northern bank, but at this point purple mudstones are seen in the bank about 10 feet from the ground. This purple band comes down to the level of the railway-line 12 yards farther on, and extends for a distance of 21 yards, occupying the whole height of the bank, with the exception of the topmost part. It then rises up again towards the top of the bank, leaving the base to be occupied by the underlying green beds of the Lower Dolgau Group. The disposition of the strata on the two sides of the cutting is best understood by an examination of the two accompanying sections (fig. 2, *a* & *b*, above), while the facts can be readily explained if we

remember that the folds pitch at a considerable angle to the southward, thus exposing higher beds in a southerly direction.

(iii) Braichodnant Stream-Section.

We have already seen that all the grit-beds of the Wenlock Series have been removed by denudation in the valley of the Iaen. To the south of that river, however, rise abruptly the steep slopes of Newydd Fynyddog, attaining to an elevation of 1400 feet. The top of this hill is capped by the massive grits belonging to the Denbighshire Series, and some of the streamlets which flow down its northern slopes present us with a complete sequence through the Nant-ysgollon Shales down to the Dolgau Beds of the main transverse section.

The westernmost of these streams is the Braichodnant, which flows almost due north into the Iaen east of Braichodnant Farm. The lower 600 yards of its course are occupied by the Dolgau Group; but the upper beds are not exposed, and the junction with the Nant-ysgollon Shales is not visible. About 300 yards from the point where the stream is joined by a small tributary we find an exposure of bluish mudstones and shales, which belong undoubtedly to the lower part of the Nant-ysgollon Shales. These have yielded at one or two horizons typical Lower Wenlock graptolites—*Monograptus vomerinus*, *M. priodon*, and *Retiolites Geinitzianus*.

Proceeding up the stream, the slope of which becomes increasingly abrupt, we find a continuous exposure of the Nant-ysgollon Shales. The upper beds are less shaly than the lower, the mudstones becoming more compact and weathering into large spheroids. These upper beds have not yielded fossils as yet.

Immediately above come the Fynyddog Grits, the junction between them and the Nant-ysgollon Shales being well seen at the bend of the stream below the point where the 1000-foot contour-line cuts it. The grits are massive, attaining a thickness of 2 to 4 feet, and, with alternations of flags and shales, they continue up to the summit of the hill. The total thickness of the Nant-ysgollon Shales in this section must be at least 500 feet, which agrees fairly well with that (450 feet) estimated in the Tarannon section.

(iv) Plas-bach Stream-Section.

The junction of the Nant-ysgollon Shales with the underlying Dolgau Beds is well seen in the stream which flows down into the Afon Iaen, near Plas-bach.

The high, steep banks of the lower part of the stream are occupied by the Upper Green Mudstones of the Dolgau Group. At a point where the 700-foot contour-line cuts the bed of the stream, a black shale-band has yielded abundant graptolites in a good state of preservation. The following species were recognized:—

Monograptus crenulatus (C).
Monograptus spiralis, Tullb. (f. C).
Monograptus cf. *nodifer* (f. C).
Monograptus speciosus (C).
Monograptus Linnarssoni (f. C).
Monograptus priodon (f. C).
Monograptus nudus (R).
Retiolites Geinitzianus (f. C).

This band undoubtedly marks the same horizon as that at the summit of the Dolgau Group described in the road-section (p. 668). Above it the Dolgau Beds pass up into the Nant-ysgollon Shales, and these in their turn into the overlying Fynyddog Grits.

(v) Stream east of Lledcwm.

The passage from the Dolgau Group into the Nant-ysgollon Shales and from those into the Fynyddog Grits may be examined in a small stream, on the south side of the hill east of Lledcwm. The uppermost band of the Dolgau Group here yields *Monograptus crenulatus*, *M. priodon*, *M. Linnarssoni*, and *Retiolites Geinitzianus*, and is overlain by typical Nant-ysgollon Shales with their characteristic fossils. In some of the higher beds of this Wenlock Group a few small brachiopods were obtained, associated with *Monograptus riccartonensis*, which appeared to be the characteristic fossil.

(vi) Afon Cwm-Calch Section.

The Afon Cwm-Calch is the main tributary of the Iaen. It rises on the Tarannon tableland near Sarn-ddu, and flows in a general north-easterly direction to join the Afon Iaen near Talerddig.

For the lower half-mile of its course its valley is occupied by various members of the Talerddig Group, which are bent into gentle undulations. The highest grit-band is shown just below the ford and small footbridge south-west of Fron; and some few yards above a thin dark shale-band, only a fraction of an inch thick and weathering to a brilliant orange tint, yields the following Talerddig species, with the local addition of the form here provisionally referred to *M. dextrorsus*, which occurs in great abundance:—

Monograptus cf. *dextrorsus* (C).
Monograptus griestonensis (f. C).
Monograptus subconicus (C).
Monograptus priodon (C).
Monograptus discus (f. C).
Monograptus nudus (f. C).
Monograptus Marri (R).

No further exposures of the Talerddig Grits are seen in the valley, but they occupy the whole of the high ground of Ffridd-yr-Ystrad on the south-east.

The Dolgau Group is exposed in the valley between this hill and that of Sarn Bigog, but its junction with the underlying Talerddig Grits is not seen. The passage between them and the overlying Nant-ysgollon Shales is, however, well exhibited in the steep and narrow gorge of Nant-ysgollon, which affords the finest and most picturesque section of these beds in the district.

These confirmatory sections prove clearly that, throughout the whole of this northern area, the lithology, the fossils, and the sequence of the strata are similar to those in the Tarannon section on the south.

(2) Western Area.

We now turn to an examination of the sections which, lying to the west of the main syncline, are exposed on the western slopes of the tableland and in the open valley of the Twymyn, which flows nearly due north in a direction parallel to the synclinal axis.

At the northern end of the Tarannon district, along the valley of the Iaen already described, we have seen that denudation has only proceeded to an extent sufficient to expose the Talerddig Grits and the underlying Gelli Beds. But in this western area it has laid bare still older groups, extending down through the base of the Tarannon Series into beds which are clearly of Llandovery (Birkhill) age.

Unfortunately, the working-out of the descending succession is rendered difficult by the effects of the lateral pressure to which the strata have been subjected. The beds belonging to the lower groups are softer and more yielding than those of the upper, and they have therefore suffered to a greater extent from folding and cleavage. Not only are they bent into sharp anticlines and synclines, but the eastern limb of these folds is generally fractured, and in some cases older beds have been thrust over newer. Nevertheless, if we disregard the local complexity of detail, we can make out the general succession of the beds as a whole, and we find that continuously-older strata meet our view as we descend from the high ground of the Tarannon tableland on the east, down to the low level of the Twymyn in the west. I will proceed first to describe some of the rock-sections exhibited in the tributary streams of the Twymyn along the western slope of the Tarannon tableland, commencing with those at the southern end near Stay-a-little.

(*a*) Sections of the Tarannon Series along the Western Slopes of the Tableland.

(i) District between Crygnant and Stay-a-little.

The sections in the southern part of this western district are for the most part short, and do not throw much light on the general sequence; but they exhibit several points of interest with regard to the lithology and fauna of the individual rock-groups.

Between Crygnant and Stay-a-little the Talerddig Grits make a prominent feature, forming the crags of Pen Cerrig-y-ffynnon, and presenting a steep scarp-face to the valley of the Afon Bachog, a tributary of the Clwyddog. All along this line are numerous small streams, which have cut narrow but deep clefts through the Gelli Shales. The rocks of the Gelli Group are here of the type described in the Tarannon section, and consist of shales and numerous small flags, with an occasional grit-band. The typical Gelli graptolites, including *Monograptus crispus*, *M. exiguus*, *M. Marri*, *M. priodon*, and *M. nudus*, were found just above a small

gravel-pit, on the hillside half-a-mile due north of Stay-a-little village. Similar forms were detected in the small stream farther south near the farm of Ddwynant-gerig, about 150 yards below the 1-foot grit-band, at the top of the section which here marks the base of the Talerddig Group.

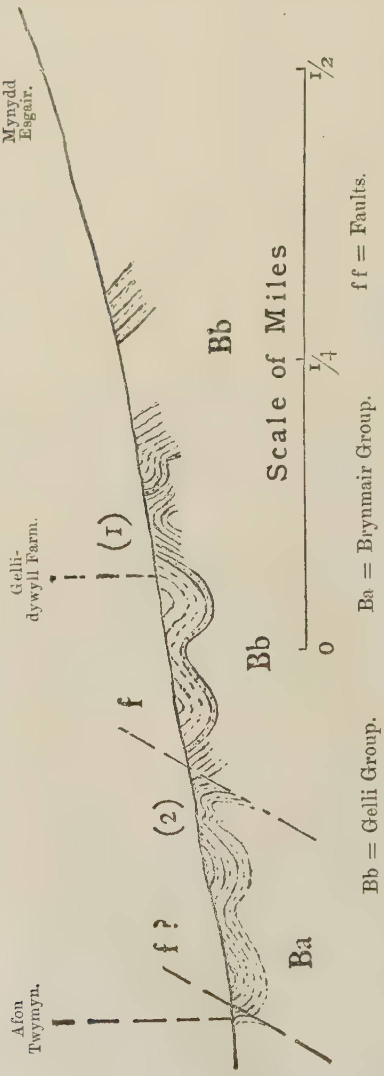


Fig. 3.—*Section along the Gelli-dywyll stream.* (*See p. 677.*)

(ii) Crygnant-Valley Section.

A longer and fairly-continuous section of the various groups, from the top of the Nant-ysgollon Shales to the top of the Gelli Shales, is exposed in the valley of the Crygnant, which rises within half-a-mile of Tarannon Farm, and joins the Twymyn near Pennant.

A good section of the Nant-ysgollon Shales, from the summit to the base, is shown in the gorge east of Cwm Mawr, and the junction with the underlying Dolgau Beds is marked by small greywacké-beds somewhat similar to those exposed along the Tarannon River. These shales have yielded the characteristic Wenlock graptolites.

Several good exposures of the various divisions of the Dolgau Group are seen in the upper part of the valley; while the Talerddig Grits form a conspicuous feature in the bed of the stream for some 200 yards above Pont Crygnant. The shales in the lower part of the Talerddig Group are too highly cleaved to afford satisfactory palæontological evidence; but, so far as one can judge, the boundary-line between these beds and the underlying Gelli Shales is approximately at Pont Crygnant.

(iii) Gelli-dywyll Stream-Section. (See fig. 3, p. 676.)

Leaving the southern part of this western area and going northward towards its centre, we find that of all the small tributary streams of the Twymyn which drain this part of the Tarannon tableland, the only one that affords a good section is that near the farm of Gelli-dywyll. The heights of Mynydd-esgair above the source of the stream are occupied everywhere by the Talerddig Grits, while the stream itself reveals a complete section of the underlying Gelli Group down into the Brynmair Beds. The Gelli Beds are, on the whole, less sandy in this central area than in the southern part of the country, and contain more mudstones and shales. Two grits, about 2 feet and 1 foot thick respectively, similar to those observed in the Tarannon section low down in the Gelli Group, occur close to the eastern gate of the farmyard, and are repeated on the east by an anticlinal fold. Some papery shales overlying these two grits yield *Monograptus crispus* (f. C), *M. priodon* (C), and *M. discus* (R) [(1) in fig. 3].

Descending the stream, we find the Gelli Beds continued to a point some 300 yards west of the farm. The strata are much folded, and have not been examined for fossils in detail; though *M. crispus* was found in abundance on the northern bank, some 70 to 80 yards below the mill-wheel. At a point (2) in fig. 3, however, where a small tributary stream enters on the northern bank, a band of dark-blue to black mudstone, dipping at an angle of 53° northwestward, yields:—

Monograptus runcinatus, mut. (C).	*Rastrites Linnæi* (young) (f. C).
Monograptus cf. *proteus* (C).	*Monograptus turriculatus* (R).
Monograptus nudus (f. C).	*Retiolites* cf. *obesus*, Lapw. (R).

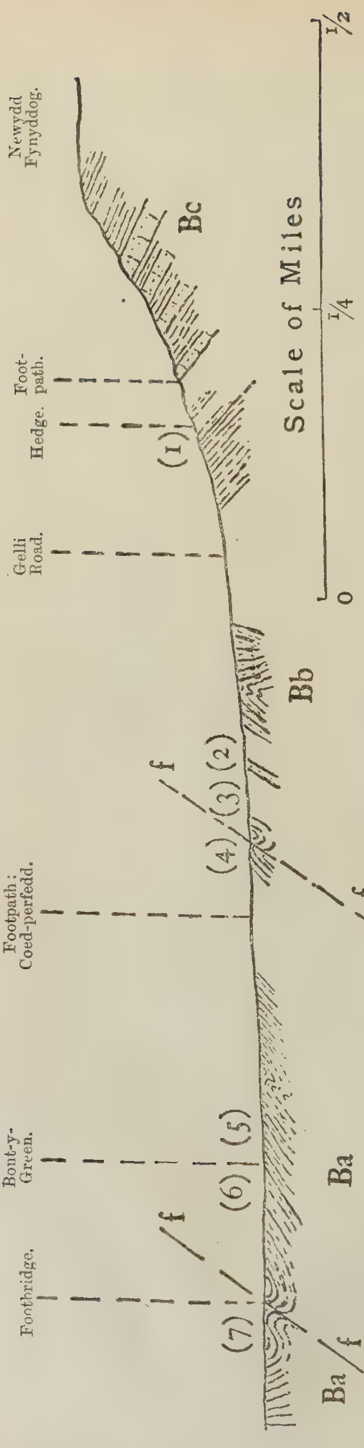
This assemblage of species has only been met with at one other locality in the district: namely, in the Twymyn, about halfway between Gelli-dywyll Mill and this Gelli-dywyll stream; and it is difficult to identify some of the forms with known species. The fauna, however, appears to indicate that these beds must be referred to a horizon fairly high up in the Brynmair or *M.-turriculatus* Group. I have provisionally drawn the boundary-line between the Gelli and Brynmair Beds above this point along a line of disturbance. The Gelli Group in this section must be at least 800 feet thick.

The Brynmair mudstones and shales are continued in gentle folds down to the junction of the stream with the Twymyn, where the beds are vertical in position; no graptolites were obtained from them.

(iv) Section in the Gelli Stream. (See fig. 4, p. 678.)

The Gelli stream north of Llanbrynmair village affords a very similar section to that just described, but here practically the complete thickness of the Brynmair Beds is shown. This small stream rises high up on the western flanks of Newydd Fynyddog, and unites with the Twymyn south of Bont-y-Green.

Fig. 4.—*Section along the Gelli stream.*



Bc = Talerddig Grits. Bb = Gelli Shales and Mudstones. Ba = Brynnair Beds. f f = Faults.

The upper part of its course, as far as the hedge which divides the moorland from the coppice and cultivated land below, is occupied by the various members of the Talerddig Group, which are well exposed and dip into the hill at 25°. In this section, the thickness of the lowest shale-band of the Talerddig Group, which is not visible in other parts of this northern and western area, is proved to be about 200 feet. At its base, (1) in fig. 4, 20 to 30 yards below the hedge, there occurs a grit 1 foot thick; and a thin shale-band immediately above it yields *Monograptus Marri* (C), *M. nudus* (C), *M. priodon*, *M. subconicus*, and *M. gemmatus (?)*.

Gelli Group (Bb).—The upper strata of the underlying Gelli Group consist of thinly-bedded shales and flags dipping south-eastward. They yield an occasional graptolite, such as *M. nudus* and *M. Marri*. For about 50 or 60 yards above and below the road which leads to the farm-house of Gelli, there are no exposures; but when the strata appear once more, they consist of dark-bluish mudstones, thickly bedded and weathering spheroidally, with some more thinly-bedded shales and occasional flags. These rocks, which resemble lithologically the Gelli Beds

as developed in the western part of the Afon-Iaen section, are continued down the stream for a distance of a quarter of a mile from the road. These lower Gelli Beds are much disturbed: at intervals they assume a vertical position, and become penetrated by quartz-veins. On the whole, however, they have a general steep north-westerly dip, and strike 20° to 50° east of north.

At one or two localities typical Gelli graptolites were obtained. At one of these (2 in fig. 4, p. 678), 350 yards below the road above mentioned, *Monograptus nudus* (C), *M. crispus* (f. C), *M. exiguus* (f. C), and *M. Marri* (C) were collected; while at another (3 in fig. 4), 80 yards below, the beds yielded *M. crispus* (f. C), *M. nudus* (f. C), and *M. discus* (R). This is an undoubted Gelli fauna, and the rarity of *M. discus* may possibly indicate that the horizon is somewhere near the base of the group.

Brynmair Group (Ba).—Another main line of disturbance is visible some 50 yards below the last-mentioned graptolitic locality, at a point where the stream makes a sharp bend; and a few feet lower down a thin band (4 in fig. 4) of shale weathering to a light orange-brown colour yields a large number of small fragments of *M. runcinatus* together with *M. nudus* (R), and one undeterminable species of *Petalograptus*. The occurrence of *M. runcinatus* in such abundance indicates that these beds belong to the Brynmair Group; and the abrupt change in fauna is highly suggestive of a fracture of some importance along the line of disturbance just mentioned. The rocks are unfortunately concealed for a distance of some 200 yards, but beyond that point to the Twymyn River there is an almost continuous exposure of pale-grey mudstones and shales, dipping at low angles of 20° to 30° north-westward. No fossils were obtained from these in the Gelli stream; but in the right bank of the Twymyn (5 in fig. 4) a soft, dark, shaly band, splitting with a curious cuboidal fracture, yields the following Brynmair graptolites in a poor state of preservation:—

Monograptus turriculatus (f. C).
Monograptus Becki, Barr. (C).
Monograptus runcinatus (?) (R).
Petalograptus palmeus, var. *tenuis*.
Rastrites Linnæi (R).

Another black-shale band, 140 yards farther down the river, is almost made up of a tangled mass of badly-preserved graptolites, including

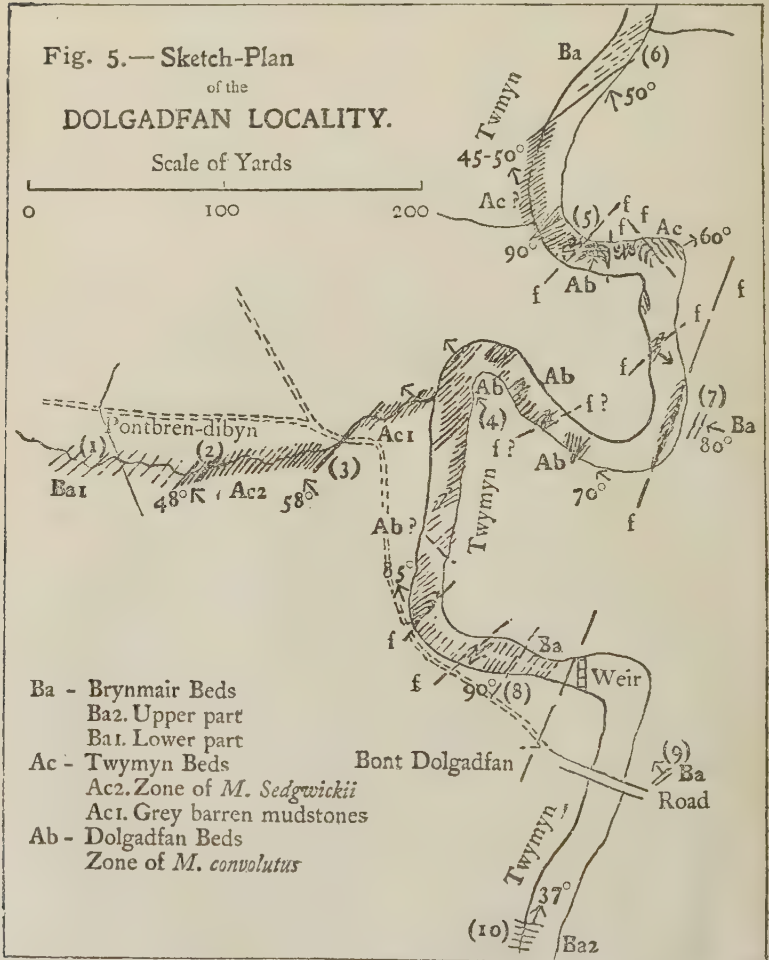
Monograptus cf. *densus* (v. C).
Monograptus cf. *runcinatus* (v. C).
Monograptus turriculatus (R).
Dendrograptus sp.

Immediately to the east of Bont-y-Green (6 in fig. 4) good specimens of *M. turriculatus*, *M.* cf. *densus*, and *M.* cf. *exiguus*[1] were obtained: the occurrence of *Monograptus exiguus* indicating that the fauna is approaching to that of the overlying Gelli Group. The beds which occupy the course of the river for the next quarter

[1] The form here referred to *Monograptus exiguus* has the typical shape of the species, but more distant thecæ than are considered characteristic.

of a mile consist of thickly-bedded, dark-blue, concretionary mudstones, with thin shale-partings. These are probably the highest beds that can be referred to the Brynmair Group; but no fossils were obtained from them at this locality.

Fig. 5.—Sketch-Plan of the DOLGADFAN LOCALITY.



In descending the river, the low dip of the beds is seen gradually to change; and, in the neighbourhood of a small footbridge fully 400 yards below Bont-y-Green, the strata, which here consist of banded grey shales, small flags, and soft dark mudstones, are either vertical in position or dip south-eastward, and show evidence of faulting and disturbance. A few yards west of the footbridge some fragments of graptolites were obtained from one thin, dark,

mudstone-band. They are too fragmentary and distorted to be identified with accuracy; but it is possible to recognize *Monograptus turriculatus* (v. R), *M.* cf. *galaensis*, Lapw. (C), *M. Halli?* (f. C), *M. proteus (?)*, and *Retiolites* sp.

This fauna is very scanty and indefinite, but it would appear to belong to the Brynmair Group, although it occupies a distinctly-lower horizon than that of the beds at Bont-y-Green. That there is here an anticlinal fold, accompanied by a fracture of some importance, is more clearly seen at the next bend of the river farther north, where the right bank is occupied by a thick mass of quartz in the neighbourhood of which the beds are much crumpled; while everywhere to the east of this quartz-vein the beds dip south-eastward.

(*b*) Sections showing the Relation of the Tarannon Series to the Llandovery Series in the Twymyn Valley.

(i) Pontbren-dibyn and the Twymyn near Dolgadfan.

The stratigraphical relation of the Tarannon to the underlying Llandovery Series is well exhibited in three sections of the Twymyn; the northernmost, and perhaps the most interesting, of these is that in the valley of the Twymyn near Bont Dolgadfan, and in the small tributary stream of the Pontbren-dibyn which joins it on its left bank. (See fig. 5, p. 680.)

Tarannon Series.

Brynmair Beds (Ba). (Zone of *Monograptus turriculatus.*)—The Pontbren-dibyn flows for the lower 300 yards of its course through a fir-plantation, about a quarter of a mile south of Llanbrynmair village. At a point in the stream less than 100 yards below the main road, and just above a small hedge on the left bank (1 in fig. 5, p. 680), some grey- and black-banded mudstones are exposed, in the darker layers of which the following graptolites were found in a good state of preservation:—

Rastrites maximus, Carr. (R).
Rastrites Linnæi (C).
Monograptus turriculatus (f. C).
Monograptus nudus (C.).
Monograptus Becki (f. C).
Monograptus subconicus? (R).
Monograptus gemmatus, Barr.
Monograptus Halli? (Barr.).
Petalograptus palmeus mut. (f. C).

The beds at this locality dip 26° north-westward. The presence of *M. turriculatus* in fair abundance fixes the age of these beds as that of the Brynmair Group; but it is interesting to find that, in addition to the forms already obtained from them, there is the well-known species *Rastrites maximus.* This has been found at this one locality only.

Llandovery Series.

Twymyn Group (Ac). (Zone of *Monograptus Sedgwickii*, Ac_2.)—Proceeding down the stream for 50 to 60 yards, we find interbedded with pale-grey shales and mudstones, and weathering to an orange-brown tint, a soft black-shale band (2 in fig. 5), which

yields an abundance of graptolites. These are generally preserved as white films; and, while the identification of some of the more abundant forms with known species was a matter of difficulty, yet it was possible to recognize:—

Monograptus distans, Portl. (v. C).	*Monograptus runcinatus* (R).
Monograptus jaculum, Lapw. (C).	*Monograptus galaensis* mut. (f. C).[1]
Monograptus discretus, Nich. (C).	*Diplograptus tamariscus*, Nich.
Monograptus Clingani, Carr. (R).	*Climacograptus scalaris*, His. (?).
Monograptus Sedgwickii, Portl. (v. C).	

Still lower down, at the point where the footpath from Llanbrynmair village to Bont Dolgadfan crosses the stream, is an exposure of intensely-black soft shale, dipping north-westward at an angle of 57° to 60° (3 in fig. 5, p. 680). This shale is carbonaceous, and blackens the fingers. It weathers to a deep orange tint, and has a curious conchoidal fracture. An extensive dip-surface is exposed, and on this the graptolites, which are preserved as whitish films, show out conspicuously. The following species are recognizable:—

Monograptus Sedgwickii (v. C).	*Diplograptus sinuatus*, Nich. (f. C).
Monograptus discretus (=*M. tenuis*, Törnq.) (v. C).	*Diplograptus tamariscus*.
Monograptus distans (?).	*Climacograptus scalaris* (f. C).

This black-shale band has a thickness of about 4 feet, but is not equally fossiliferous throughout. It crops out again on the south side of the footpath, and in the bed of the stream below the footbridge; and, between that point and the Twymyn River, the rocks laid bare consist of light-coloured brownish-grey shales and mudstones containing patches of carbonaceous matter, but with no distinct black layers.

Thus, rising out from below the Brynmair Beds we find an uninterrupted succession of about 140 feet of grey shales and mudstones, with at least two black shale-bands. The faunas of these bands have several species in common, and may be referred to one zone which, on account of the great abundance of *M. Sedgwickii*, may be appropriately called the local zone of *Monograptus Sedgwickii*. Here, for the first time in the descending order of beds in this district, do we find a graptolitic fauna which is acknowledged to be of Upper Llandovery age—namely, that of the Upper Birkhill Shales of Southern Scotland and of the Caban Group of Rhayader; and we have, therefore, descended below the base-limit of the Tarannon Series. I term these beds the Twymyn Group; and they constitute the highest member of the Llandovery Series of this district, as distinct from the overlying Tarannon Series. The Twymyn Group may be here divided into:—(1) *M.-Sedgwickii* Beds (Ac_2), with two fossiliferous bands (90 feet); and (2) palegrey mudstones (Ac_1) (50 feet), containing no fossils at this locality.

Dolgadfan Group (Ab). (Zone of *Monograptus convolutus*.)—The Lower Twymyn pale mudstones are continued in the bed of the

[1] The form here named provisionally '*Monograptus galaensis* mut.' occurs in the *M.-Sedgwickii* Beds of the South of Scotland, and is probably a new variety.

main Twymyn River for a few yards, but soon become intermixed with black shale-bands. Two of these exposed in the eastern bank at point 4 in the plan, fig. 5, p. 680, yield :—

Monograptus convolutus, His. (f. C).
Monograptus gregarius, Lapw. (f. C).
Monograptus communis mut. (f. C).
Monograptus leptotheca, Lapw. (R).
Monograptus triangulatus (?) His.
Climacograptus scalaris (C).
Diplograptus sinuatus (f. C).
Petalograptus minor, Elles (R).

These beds dip steadily in a north-westerly direction under the Twymyn Group, and must therefore be on a lower horizon. The fauna is essentially distinct from that of the '*Sedgwickii*'-Beds, for of eight species only two survive into the higher zone. They should therefore be regarded as constituting part of a distinct group of the Llandovery Series, which may be termed the Dolgadfan Group, from the neighbouring hamlet. The characteristic graptolite of its fauna is *Monograptus convolutus*, which has consequently been selected as the local zone-fossil.

Continuing the section down the valley, we find the Twymyn turning sharply to the east, and along this east-and-west reach of the river the Llandovery rocks present much the same lithological character of finely-banded grey and black shales and mudstones. They are, however, much folded and fractured and penetrated by quartz-veins, although the general dip is 70° to 90° northwestward. Such few graptolites as were obtained were clearly of the Dolgadfan type.

Leaving this part of the river, and going farther down to the point 5 (see fig. 5, p. 680) where the river flows westward, we find exhibited along the northern bank the nose of an anticlinal fold, much faulted. Almost in the centre of this fold a thin black shale-band, splitting into layers no thicker than a sheet of paper, yields an abundance of well-preserved graptolites. The following species are present :—

Monograptus leptotheca (v. C).
Monograptus cf. *decipiens*, Törnq. (v. C).
Monograptus gregarius (C).
Monograptus harpago, Törnq. (f. C).
Monograptus convolutus (R).
Monograptus nuntius, Barr. (R).
Climacograptus Hughesi, Nich. (=*undulatus*, Kurck.) (C).
Climacograptus scalaris.
Petalograptus palmeus.
Petalograptus ovato-elongatus, Kurck. (f. C).
Petalograptus minor, Elles.
Cephalograptus petalum, Elles.
Diplograptus magnus, H. Lapw. (f. C).
Diplograptus bellulus, Törnq.
Diplograptus sinuatus (?).

This fauna, though much richer in species, has considerable similarity to that of the zone of *Monograptus convolutus* already described, and may be referred to the same zone; but it is sufficiently distinct to be regarded as marking another, and probably lower, band in that zone.

Immediately to the east of this anticlinal axis, and faulted against the Dolgadfan Beds, occur thick black shales which both in lithology and in fauna clearly belong to the overlying '*Sedgwickii*'-Beds. They yield *Monograptus Sedgwickii* and *M. discretus*. The beds are much disturbed, but dip off the anticline at high angles north-eastward.

Passing now to the other and west side of the anticline, we find that, as the river bends to the north, the beds gradually pass from a vertical position to a steady dip of 40° or 50° north-westward. Finely-banded grey and black shales and mudstones are exposed in the bed and left bank of the river, but they are accessible only when the water is at a very low level. At a point between 80 and 90 yards due north of 5 in fig. 5, p. 680, and immediately to the south of a small tributary stream (6 in fig. 5) on the right bank, a fossiliferous band yields characteristic Lower Brynmair species:—

Monograptus turriculatus (v. C).	*Monograptus regularis*, Törnq. (R).
Monograptus runcinatus (v. C).	*Monograptus Halli* (R).
Monograptus jaculum (f. C).	*Petalograptus minor* (R).
Monograptus nudus (f. C).	*Climacograptus scalaris* (f. C).
Monograptus Becki (?).	*Diplograptus tamariscus ?* (f. C).
Monograptus involutus, Lapw. (?) (f. C).	

Thus, although the Twymyn Beds have not yet been actually detected in this section, it is practically certain that on this western limb of the anticline there is, as in the Pontbren-dibyn, a continuous and undisturbed sequence from the Dolgadfan Group up to the Brynmair Group.

Returning to the eastern limb of the anticline, we find that the '*Sedgwickii*'-Beds are cut off abruptly on the east, by a line of great disturbance which is visible all along the eastern bank of the river, the beds being twisted up, faulted, and penetrated by quartz-veins of considerable size. The right bank at this point (7 in fig. 5, p. 680) is high, and is occupied by Brynmair mudstones and shales dipping at a steep angle north-westward. They yield:—

Monograptus cf. *densus* (v. C).	*Monograptus gemmatus (?).*
Monograptus proteus (R).	*Rastrites Linnæi (?).*
Monograptus nudus (R).	

The fauna, although not very distinctive, appears to show that these beds occupy a horizon fairly high up in the Brynmair Group.

Thus, in the valley of the Twymyn at this locality, the Llandovery Beds are folded into a sharp and broken anticline. The Dolgadfan Beds (zone of *M. convolutus*), represented by two bands, occupy the centre, and are followed on the west side in perfectly conformable succession by the Twymyn Beds (zone of *M. Sedgwickii*), and these in their turn by the Lower Brynmair Beds (zone of *M. turriculatus*). On the east side the '*Sedgwickii*'-Beds are seen in part, but they are faulted against the Upper Brynmair Beds, the whole of the lower portion of the group being cut out.

Additional sections are exhibited in the bed of the Twymyn between the point last described and Bont Dolgadfan, but they have not been examined in detail, owing to the difficulty of access to the exposures. The relations of the beds are therefore only indicated generally on the sketch-map (fig. 5, p. 680). Somewhat older Brynmair Beds, containing *Rastrites Linnæi*, *R. hybridus (?)*, *Monograptus runcinatus*, *M. gemmatus*, *M. Becki (?)*, and *Diplograptus tamariscus*, occur some few yards below the weir (8 in fig. 5), and *Rastrites Linnæi* was found in fair abundance on the north side of the road to the east of the bridge (9 in fig. 5); while

the typical Upper Brynmair mudstones, as exhibited near Bont-y-Green, occupy about three quarters of a mile of the Twymyn Valley to beyond Gelli-dywyll Mill. Near Bont Dolgadfan (10 in fig. 5, p. 680) these beds dip 37° almost due north, and contain abundant examples of *Monograptus* cf. *densus*.

(ii) Afon Fachdre, Pennant. (See fig. 6, p. 686.)

Farther up the Twymyn Valley other important exposures occur, showing the relationship of the Brynmair Group to the older Llandovery Beds. These are exhibited in the Twymyn and its tributary the Afon Fachdre, near the hamlet of Pennant, about 2 miles south of Dolgadfan.

Brynmair Group (Ba).—The bed of the Twymyn, from Pont-bren Llam to the Pennant factory, is occupied by the typical mudstones of the Upper Brynmair Group, which are arranged in gentle undulations, the dip varying in amount from 8° to 10°, and the strike swinging round through an angle of 90°. A few yards to the north-east of the factory itself, a small thrust-fault with a low hade is seen in the left bank, the crush-band being 1·6 to 2 feet in width. The throw of this particular fault is slight, for the beds on both sides are similar in lithological character; but it is significant, as indicating the type of movement met with in this part of the district. These Brynmair strata (1 in fig. 6, p. 686) afford graptolites in the thin shale-partings between the mudstone-beds, including *Monograptus* cf. *exiguus* (v. C), *M.* cf. *densus* (C), *M. turriculatus* (R), *M. nudus* (f. C), and *Petalograptus palmeus*, var. *tenuis*.

Dolgadfan Group (Ab). (Zone of *Monograptus fimbriatus*, Ab_1.)—Leaving the main river, and ascending the tributary of the Fachdre, we find these Upper Brynmair mudstones exposed in the stream for some 50 or 60 yards. On the northern bank, however, at the point where the brook turns abruptly to the south, and quite close to the old Mill-wheel (2 in fig. 6, p. 686), we come suddenly upon older rocks of a different lithological type, much contorted and disturbed. They consist of finely-banded mudstones and shales, weathering deeply to an ashen-grey tint, and stained orange: they yield an abundance of graptolites in some of the darker seams. The following species were identified:—

Monograptus fimbriatus, Nich. (v. C).
Monograptus gregarius (f. C).
Climacograptus Hughesi (C).
Climacograptus rectangularis (f. C).
Climacograptus scalaris (C).
Diplograptus magnus (C).
Diplograptus tamariscus (f. C).
Diplograptus parvulus, H. Lapw.? (C).
Petalograptus minor (f. C).

This fauna possesses so many features in common with that of the Dolgadfan Beds (zone of *M. convolutus*), that there can be no hesitation in including these deposits with the Dolgadfan Group; but the rarity of species of *Monograptus*, and the great preponderance of Climacograptids and Diplograptids, point clearly to the probability of these beds belonging to a lower horizon in that group. The abundance of *M. fimbriatus* naturally suggests that

these beds should be distinguished as the zone of *Monograptus fimbriatus.*

At this point there must be, as in the Twymyn near Dolgadfan, a fault dividing the Llandovery Beds from the Tarannon, but having a still greater throw.

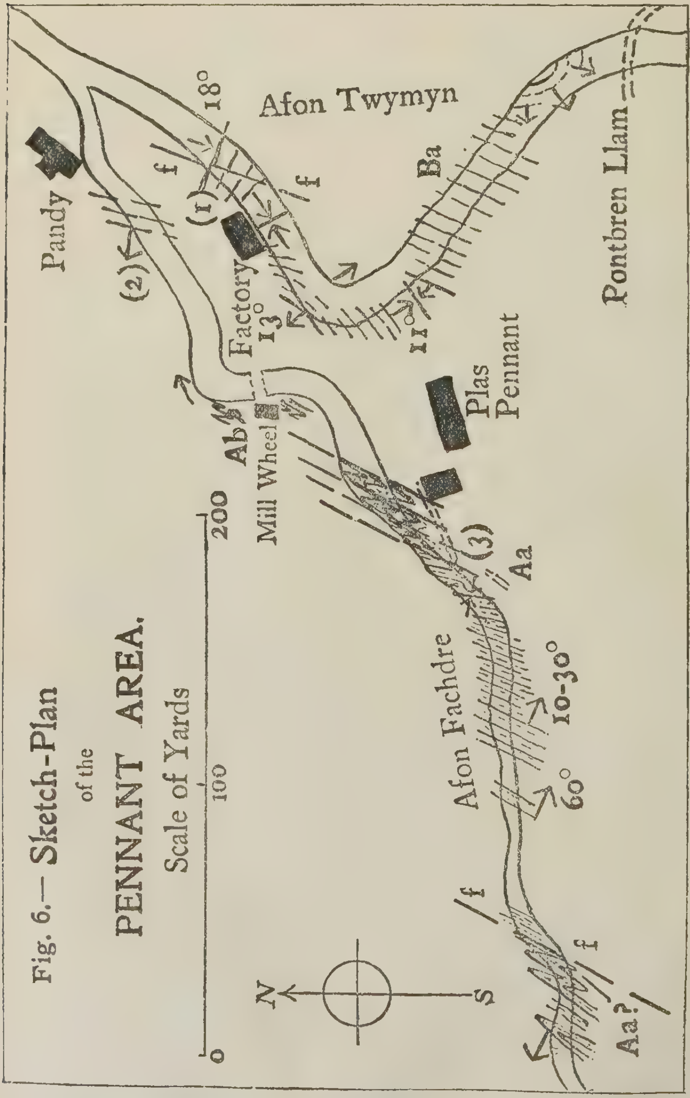


Fig. 6.— Sketch-Plan of the PENNANT AREA.

Ba = Brynmair Beds (Upper Mudstones). Ab = Dolgadfan Beds (Zone of *Monograptus fimbriatus*).
Aa = Fachdre Beds (Zone of *Dimorphograptus Swanstoni*).

Fachdre Beds (Aa). (Zone of *Dimorphograptus Swanstoni.*)— Wherever the rocks are seen to the west of this locality, they

are in a more or less vertical position, and much disturbed. In the bed and northern bank of the Fachdre below Plas Pennant, papery but rather sandy shales, compact calcareous mudstones, and small flags are twisted up, folded, and faulted. Some of the darker shaly bands yielded a few poor fragments of *Climacograptus rectangularis* and *Cl. scalaris*, while just below the path from the farmhouse down to the stream (3 in fig. 6, p. 686), Miss Elles was fortunate enough to hit upon a fossiliferous band among some dark sandy mudstones, which yields in relief :—

Dimorphograptus Swanstoni, Lapw. (v. C).
Climacograptus medius, Törnq. (v. C).
Climacograptus Hughesi ? (R).
Diplograptus vesiculosus, Nich. (v. R).
Monograptus tenuis, Portl. (f. C).
Orthoceras sp.

This fauna is so distinct from any detected elsewhere in the district, that it must not only constitute a special zone, but must also be referred to a fresh group of strata, for which I suggest the name of Fachdre. This Fachdre Group constitutes the lowest member of the Llandovery Series found in the Tarannon district, and may be distinguished as the zone of *Dimorphograptus Swanstoni*. It must have a thickness of 100 to 150 feet. Its junction with the overlying Dolgadfan Beds is obscure in this section.

No further palæontological evidence has been obtained from the rocks in the upper part of the Fachdre Valley. The beds are at first much disturbed, but gradually assume a north-westerly dip; and, judging from graptolitic evidence obtained in the Conroy Valley, only a third of a mile to the north, there can be little doubt that the various members of the Llandovery and Tarannon Series, at any rate as high as the Brynmair Beds, will be found again to the west.

Thus, in this Afon-Fachdre section, the Upper Brynmair Beds with their usual characters are seen to be faulted against a broken anticline of Llandovery strata on the east, but to follow them conformably on the western side.

Although the Lower Brynmair Beds are faulted out in the Fachdre section, yet they come in again much disturbed a quarter of a mile higher up the Twymyn Valley, where they yield *Rastrites Linnæi*, *Monograptus runcinatus*, *M. jaculum*, and *M. turriculatus*; and some 200 yards to the west, Fachdre Beds are exposed at the corner of the road from Pennant to Pentre Cil-cwm. Here *Monograptus tenuis* and *Climacograptus medius* were obtained from some sandy micaceous shales, weathering to a bright reddish-orange tint, and associated with flags of 2 to 3 inches in thickness.

No sections are seen in the valley of the Twymyn for the next mile and a half of its course, but west of the river, along the road to the north-east of Pennant-isaf, there is an exposure of Llandovery rocks, possibly referable to the *Monograptus-fimbriatus* zone. The graptolites, which are wretchedly preserved, include the following :—

Climacograptus scalaris (C).
Climacograptus rectangularis (f. C).
Monograptus fimbriatus ? (f. C).
Monograptus triangulatus ? (f. C).
Monograptus regularis (R).
Monograptus tenuis (R).

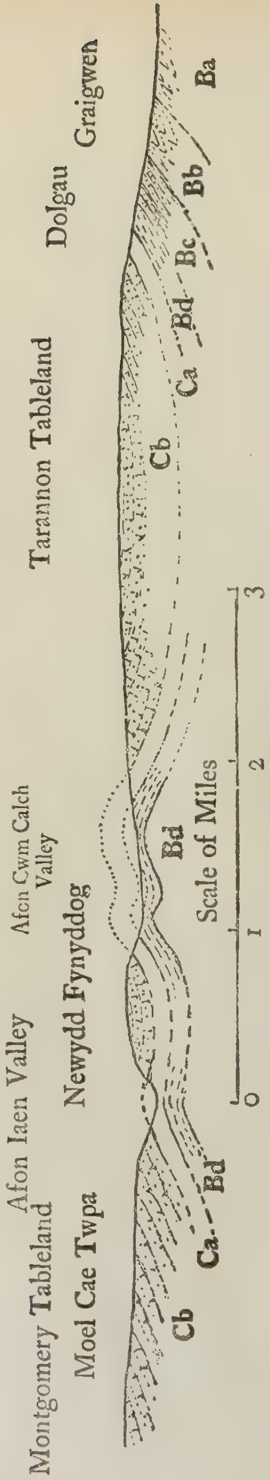


Fig. 7.—*Longitudinal section through the Tarannon district.* (*See pp. 652 & 689.*)

Cb = Fynyddog Grits. Bd = Dolgau Group. Bb = Gelli Group.
Ca = Nant-ysgollon Shales. Bc = Talerddig Group. Ba = Brynmair Group.

(iii) The Twymyn below Craig-y-Maes.

South of the farmsteads of Pennant-isaf and Pennant-uchaf the valley of the Twymyn narrows to a deep gorge, and a continuous section is seen in the bed of the river for fully half a mile, while the crags of Maes and Foel, on either side, afford excellent rock-exposures to the climber. The part occurring between the small footbridge at the extreme northern end and a small tributary stream on the right bank, which has cut a deep and precipitous gorge from the top of Foel down to the main river—a height of nearly 600 feet—has been examined only in a general way, sufficient to satisfy myself that the sequence, fossils, and structure of the strata in this southern part of the Twymyn Valley correspond with those observed elsewhere.

The beds here exposed consist of the Llandovery strata and part of the overlying Brynmair Shales, and they are bent into a main anticlinal fold, with numerous subsidiary undulations and fractures. As in the other sections already described, there is a normal sequence of rocks on the western limb, while some of the beds are faulted out on the eastern side.

The Brynmair Beds consist here of pale greenish-grey mudstones stained with manganese, and hardly distinguishable in mineralogical character from the Upper Dolgau mudstones. At their base a dark shale-band, dipping at 45° north-westward, yields:—

Monograptus distans ? (C).
Monograptus cf. *Becki* (f. C).
Monograptus Halli (R).
Monograptus regularis (R).
Petalograptus palmeus (R).
Climacograptus extremus, H.Lapw. (C).

Judging from the fauna, this band is close to the junction of the Twymyn and Brynmair Groups.

A complete sequence through the whole of the Twymyn Beds is shown in this section, and they must have a thickness of about 150 feet. Another fossiliferous band is found at the base of the Lower Twymyn Beds, about 200 yards north of the tributary stream, and south of a small group of trees on the right bank: here a black shale-band rich in iron-pyrites yields:—

Rastrites peregrinus, Barr. (C).
Monograptus regularis (C).
Monograptus crenularis, Lapw. (C).
Monograptus harpago (v. C).
Monograptus limatulus, Törnq. (C).
Monograptus decipiens (?) Törnq. (f. C).
Climacograptus Hughesi (C).
Climacograptus scalaris.
Diplograptus tamariscus.

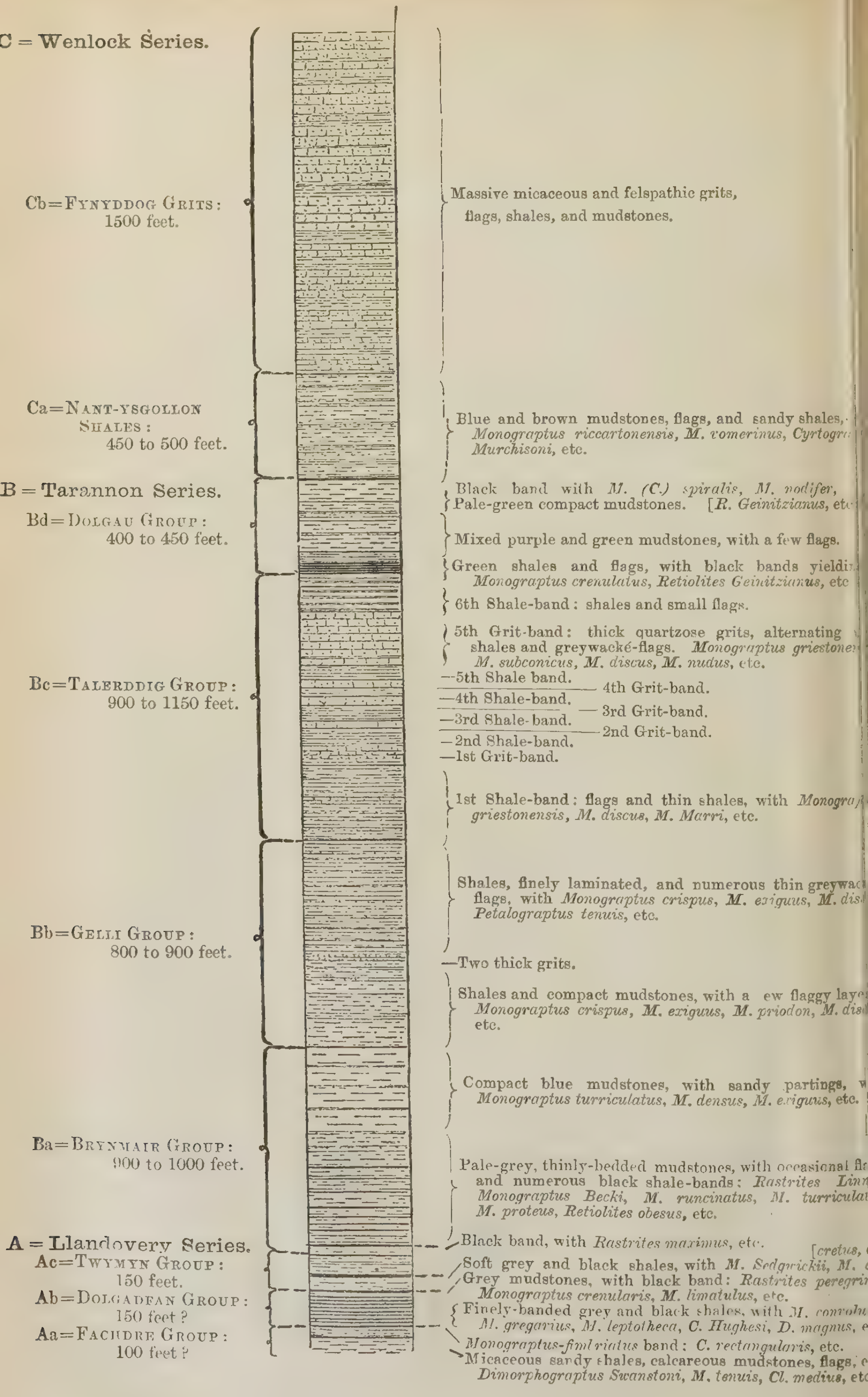
This assemblage of species corresponds to that of the zone of *Cephalograptus cometa*, which elsewhere in Britain, and in Scania, underlies the zone of *Monograptus Sedgwickii*.

The axis of the main Twymyn anticlinal fold is seen still higher up the river, while the junction of the Twymyn Beds with the Brynmair Group on the eastern limb of the fold is well exhibited about one-third of the way up the gorge of the tributary stream. Here the '*Sedgwickii*'-Beds, containing the characteristic graptolites, are folded and faulted against Brynmair Shales which have yielded:—*Monograptus Halli*, *M. nudus*, *Petalograptus palmeus* var. *tenuis*, *Rastrites Linnæi*, *Retiolites* cf. *obesus*, and other typical forms. The Brynmair Beds occupy the whole of this gorge up to the top of Foel, and must have a thickness of at least 700 to 900 feet. They are arranged in a synclinal form, which may account for the hill of Foel intervening between the valleys of the Twymyn and the Crygnant.

Summarizing the results arrived at by the examination of the sections in the western part of the district, we find that, as we pass from the heights of the Tarannon tableland on the east to the valley of the Twymyn on the west, there is a complete descending sequence of strata from the Wenlock Series at the summit, through the Tarannon Series along the flanks, down to the Llandovery Series at the base. Unlike the higher beds at the top of the tableland, which are arranged in a synclinal form, the lower beds are irregularly disposed on both sides of a broken anticline running more or less parallel to the course of the river-valley of the Twymyn. The general arrangement of the strata is shown in the accompanying generalized sections (fig. 7, p. 688 & Pl. XLVIII, fig. 2).

Note on the Eastern Area.—We have now completed our survey of the various sections exposed in the Tarannon district, with the exception of those on the eastern flanks of the Tarannon tableland in the direction of Carno. In this area, however, the rocks are so folded as to result in the repetition of the Talerddig group of strata for great distances. Most of the streams, too, are entirely occupied by Drift, and exhibit no rock-exposures—it has therefore been necessary to map the boundaries between the formations almost entirely by the form of the ground. None of the sections throw additional light, either on the sequence of the strata or on the structure of the country, and they need not therefore be described.

Fig. 8.—*Generalized vertical section of the strata in the Tarannon district.*



III. General Summary.

(A) The Tarannon Sequence.

Having completed the examination of the more important sections in the Tarannon District, we may now summarize the results achieved with regard not only to the lithological, but also to the palæontological characters of the rocks, and compare them with their equivalents elsewhere.

We have seen that, in this Tarannon area, resting conformably on Llandovery rocks below and passing up without a break into Wenlock Beds above, occurs a series of strata some 3000 to 3500 feet in thickness. This great rock-series, which we term the Tarannon Series, is stratigraphically continuous from base to summit, and includes the four divisions of the Brynmair, Gelli, Talerddig, and Dolgau Groups, which, while they possess distinctive features of their own, are bound together by common palæontological characteristics.

The Brynmair Group (zone of *Monograptus turriculatus*), which constitutes the lowest division of the Tarannon Series, consists of pale to dark-grey mudstones and shales, with only occasional bands of flaggy material. In the overlying Gelli Group (zone of *Monograptus crispus*), the sediments become somewhat coarser in character, but they vary in different parts of the district. In the south, sandy flags and well-laminated shales occur in almost equal proportions; but in the north-west mudstones and shales predominate. The Talerddig Group (zone of *Monograptus griestonensis*) above is essentially a sandy one, and contains numerous bands of thick grit which are generally massed together at four or five distinct horizons. As with the underlying Gelli Group, its sediments become finer as a whole when followed to the north. The highest member of the Tarannon Series, namely the Dolgau Group (zone of *Monograptus crenulatus*) (local Tarannon Shales of the Geological Survey), consists of pale-green mudstones and shales interbedded with a varying number of purple bands. These purple bands are very prominent in the southern part of the district, but almost disappear as they are traced north-westward, where their place is taken by bands of a green tint.

The Tarannon Series is overlain with complete conformity by the Wenlock Series, which in this district consists of a lower shaly division—Nant-ysgollon Group (zones of *Cyrtograptus Murchisoni* and *Monograptus riccartonensis*); and an upper and coarse gritty division—the Fynyddog Group, or Denbighshire Grits, having a collective thickness of 1500 feet.

The Tarannon Series passes down, also without a break, into the Llandovery Series, which has at present been recognized in this district only in the centre of the Twymyn Valley. The Llandovery sediments are formed of finer material, and their component divisions are much thinner than those of the overlying Tarannon and Wenlock Series, and collectively only 300 or 400 feet thick. Three divisions

are recognizable:—The highest or the Twymyn Group consists of pale mudstones, with occasional black shale-bands. It contains two zones, namely those of *Monograptus Sedgwickii* and *Cephalograptus cometa*. It passes down with complete conformity into the Dolgadfan Group (zones of *Monograptus convolutus* and *M. fimbriatus*), the sediments of which are fairly similar to those of the overlying group but contain more numerous black bands. The lowest beds yet detected in the district constitute the Fachdre Group (zone of *Dimorphograptus Swanstoni*), and consist mainly of sandy or calcareous mudstones with some gritty bands.

(B) Comparisons with the Graptolitic Deposits of other Areas.

(*a*) Palaeontological.

With the exception of two small brachiopods, an *Orthoceras*, a doubtful trilobite, and abundant worm-burrows, the only fossils hitherto found in this Tarannon district are graptolites. These are, however, numerous both as regards individuals and as regards species. The identification of several forms has been rendered difficult, partly on account of their imperfect preservation, and partly from our lack of exact knowledge concerning many of the species found at corresponding horizons in other parts of Britain. Hence the comparison of the graptolites, based as it is on imperfect lists, is by no means so complete and satisfactory as it would otherwise be.

The accompanying Tables illustrate the geological range of the various species of graptolites found in the Tarannon district and their geographical distribution. In Table I the species are arranged in the first column in alphabetical order; in Table II they are arranged so as to show, as far as possible, their order of appearance in the Tarannon country. The relative abundance of the species is also denoted by letters, as without this it is almost impossible to form a correct idea of the distinctiveness of the local zones.

Examining these lists generally, we can have no hesitation in paralleling the Llandovery Series of the Tarannon district with the Birkhill Beds of the South of Scotland, the Tarannon Series with the Gala Group, and the Wenlock Series with the Riccarton Beds.

Before discussing the question of the fauna of the Tarannon Series, we may briefly consider that of the underlying Llandovery Series. Out of the total number of 39 species found in this series, 29 are known to occur in the Birkhill Shales, and the remaining 10 are forms which have been described since the Birkhill Shales were originally zoned by Prof. Lapworth.

Considering first the Fachdre Beds, we find it possible to institute a close comparison between their fauna and that of the highest band of the zone of *Diplograptus vesiculosus* in the Moffat District. This band is there, here, and elsewhere, characterized by the presence of species of *Dimorphograptus* and by the occurrence of the first known Monograptid, namely *Monograptus tenuis*.

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TABLE II.—COMPARATIVE TABLE OF THE GRAPTOLITES OF THE TARANNON DISTRICT, SHOWING THEIR GEOLOGICAL RANGE AND DISTRIBUTION. (The species arranged in their order of appearance.)

r = rare.
f = fairly common.
C = common.

TARANNON DISTRICT.

Species	Llandovery Series. Fachdre Beds. Zone of *Dimorphograptus Swanstoni*.	Dolgadfan Beds. Zone of *Monograptus fimbriatus*.	Dolgadfan Beds. Zone of *M. convolutus*.	Twymyn Beds. Zone of *Cephalograptus cometa*.	Twymyn Beds. Zone of *M. Sedgwickii*.	Tarannon Series. Brynmair Beds. Band with *Rastrites maximus*.	Brynmair Beds. Zone of *M. turriculatus*.	Gelli Beds. Zone of *M. crispus*.	Talerddig Grits. Zone of *M. griestonensis*.	Dolgau Beds. Lower Zone of *M. crenulatus*.	Dolgau Beds. Upper Zone of *M. crenulatus*.	Wenlock Series. Nant-ysgollon Shales. Zone of *Cyrtograptus Murchisoni*.	Nant-ysgollon Shales. Zone of *Monograptus riccartonensis*.	Fynydd Grits. Denbighshire Grits.
Monograptus riccartonensis, Lapw.												r	C	
Cyrtograptus Murchisoni, Carr.												f		
,, *Lapworthi*, Tullb.												r		
Monograptus continens, Törnq.												?		
,, *vomerinus*, Nich.											?	C		
,, *Linnarssoni*, Tullb.											f	r		
,, *(Cyrtograptus) spiralis*, Tullb.											f			
,, *speciosus*, Tullb.											C			
,, cf. *nodifer*, Törnq.											f			
Retiolites Geinitzianus, Barr.										f	f	C		
Monograptus crenulatus, Törnq.									r	f	C	r		
,, cf. *dextrorsus*, Linnr.									f					
,, *griestonensis*, Nicol									C	r				
,, *discus*, Törnq.								f	C	r				
,, *crispus*, Lapw.								C						
,, *exiguus*, Nich.							f	C	?					
,, cf. *densus*, Perner							C	?						
,, *proteus*, Barr.							C							
,, *runcinatus*, Lapw., mut.							C							
Retiolites cf. *obesus*, Lapw.							r							
Monograptus Marri, Perner							?	C	C	r	r			
,, *priodon*, Bronn							f	C	C	C	C	C		
,, *involutus* (?) Lapw.							?							
Rastrites hybridus, Lapw.							?							
Petalograptus palmeus, var. *tenuis*, Barr.							f	f						
Monograptus nudus, Lapw.						C	f	C	C	r	r			
,, *gemmatus*, Barr.						r	r	?	?					
Rastrites Linnæi, Barr.						C	C							
,, *maximus*, Carr.						f								
Petalograptus palmeus, Barr., var.						C								
Monograptus subconicus, Törnq.						?	?	f	C	r				
,, *turriculatus*, Barr.						f	C	r						
,, *Becki*, Barr.						f	C							
Dendrograptus sp.							r							
Climacograptus extremus, H. Lapw.						C								
Monograptus runcinatus, Lapw.					r		C							
,, *jaculum*, Lapw.					C		f							
,, *Halli*, Barr.					?	r	r							
,, *galaensis*, Lapw., mut.					f									
,, *distans*, Portl.					C	C?								
,, *Clingani*, Carr.					r									
,, *Sedgwickii*, Portl.					C									
,, *discretus*, Nich.					C									
,, *limatulus*, Törnq.				C										
,, *crenularis*, Lapw.				C										
Rastrites peregrinus, Barr.			f	C										
Monograptus cf. *decipiens* (?) Törnq.			C	f										
Petalograptus palmeus, Barr.			C											
Monograptus harpago, Törnq.			f	C										
Diplograptus sinuatus, Nich.			f		f									
Monograptus communis, Lapw., mut.			f											
,, *convolutus*, His.			f											
,, *nuntius*, Barr.			r											
Petalograptus ovato-elongatus, Kurck.			f											
Cephalograptus petalum, Elles			r											
,, *bellulus*, Törnq.			r											
Monograptus attenuatus (?) Hopk.			r											
,, *leptotheca*, Lapw.			C											
Diplograptus tamariscus, Nich.		f	f		f	f								
Monograptus regularis, Törnq.		f	?	C	r		r							
,, *gregarius*, Lapw.		f	C											
Petalograptus minor, Elles		f	f											
Monograptus triangulatus, His.		?	?											
Diplograptus magnus, H. Lapw.		C	f											
,, *parvulus*, H. Lapw. (?)		C												
Monograptus fimbriatus, Nich.		C												
Climacograptus Hughesi, Nich.	?	C	C	C	f									
,, *rectangularis*, M'Coy	C	f	f											
Monograptus tenuis, Portl.	f	r												
Climacograptus medius, Törnq.	C													
Dimorphograptus Swanstoni, Lapw.	C													
Diplograptus vesiculosus, Nich.	r													
Climacograptus scalaris, His.	C	C	C	f	f	r								

RHAYADER DISTRICT.

Species	Gwastaden Group. Dôl Shales. Zone of *Monograptus tenuis*.	Dôl Shales. Zone of *M. cyphus*.	Zone of *M. fimbriatus*.	Gigrin Mudstones. Calcareous-Nodule Beds.	Gigrin Mudstones. Zone of *M. convolutus*.	Gigrin Mudstones. Pale-grey Mudstones.	Caban Group. Caban Conglomerate. Lower Conglomerate.	Caban Conglomerate. Intermediate Shales.	Caban Conglomerate. Upper Conglomerate.	Gafallt Beds. *M.-Sedgwickii* Grits.	Gafallt Beds. Gafallt Shales.	Rhayader Pale Shales. Lower Rhayader Beds.	Rhayader Pale Shales. Upper Rhayader Beds.
Monograptus riccartonensis, Lapw.													
Cyrtograptus Murchisoni, Carr.													
,, *Lapworthi*, Tullb.													
Monograptus continens, Törnq.													
,, *vomerinus*, Nich.													
,, *Linnarssoni*, Tullb.													
,, *(Cyrtograptus) spiralis*, Tullb.													
,, *speciosus*, Tullb.													
,, cf. *nodifer*, Törnq.													×
Retiolites Geinitzianus, Barr.													
Monograptus crenulatus, Törnq.													
,, cf. *dextrorsus*, Linnr.													
,, *griestonensis*, Nicol													
,, *discus*, Törnq.													×
,, *crispus*, Lapw.													×
,, *exiguus*, Nich.													×
,, cf. *densus*, Perner													
,, *proteus*, Barr.										×	×		
,, *runcinatus*, Lapw., mut.													
Retiolites cf. *obesus*, Lapw.													×
Monograptus Marri, Perner													×
,, *priodon*, Bronn													×
,, *involutus* (?) Lapw.										×			
Rastrites hybridus, Lapw.										?			
Petalograptus palmeus, var. *tenuis*, Barr.													
Monograptus nudus, Lapw.												×	
,, *gemmatus*, Barr.					?								×
Rastrites Linnæi, Barr.													
,, *maximus*, Carr.													
Petalograptus palmeus, Barr., var.													
Monograptus subconicus, Törnq.										×		?	
,, *turriculatus*, Barr.												×	
,, *Becki*, Barr.												×	
Dendrograptus sp.													
Climacograptus extremus, H. Lapw.												×	
Monograptus runcinatus, Lapw.												×	
,, *jaculum*, Lapw.												×	
,, *Halli*, Barr.												×	
,, *galaensis*, Lapw., mut.													
,, *distans*, Portl.												×	
,, *Clingani*, Carr.										×			
,, *Sedgwickii*, Portl.										×	×	×	
,, *discretus*, Nich.													
,, *limatulus*, Törnq.													
,, *crenularis*, Lapw.			×	×	×		×						
Rastrites peregrinus, Barr.				×									
Monograptus cf. *decipiens* (?) Törnq.										?			
Petalograptus palmeus, Barr.			×	×									
Monograptus harpago, Törnq.										?			
Diplograptus sinuatus, Nich.			×							×			
Monograptus communis, Lapw., mut.			×		?								
,, *convolutus*, His.					×					×			
,, *nuntius*, Barr.					×								
Petalograptus ovato-elongatus, Kurck.													
Cephalograptus petalum, Elles													
,, *bellulus*, Törnq.					×								
Monograptus attenuatus (?) Hopk.		×	×	×									
,, *leptotheca*, Lapw.			×	×									
Diplograptus tamariscus, Nich.			×	?	×								
Monograptus regularis, Törnq.													
,, *gregarius*, Lapw.			×	×									
Petalograptus minor, Elles			×										
Monograptus triangulatus, His.			×										
Diplograptus magnus, H. Lapw.			×	×									
,, *parvulus*, H. Lapw. (?)													
Monograptus fimbriatus, Nich.			×										
Climacograptus Hughesi, Nich.			×	×	×								
,, *rectangularis*, M'Coy	×	×	×	×									
Monograptus tenuis, Portl.	×												
Climacograptus medius, Törnq.													
Dimorphograptus Swanstoni, Lapw.													
Diplograptus vesiculosus, Nich.													
Climacograptus scalaris, His.	×	×	×		×	×	×	×		×			

LAKE DISTRICT. — SOUTHERN SCOTLAND (MOFFAT, &c.).

Species	Lake District. Stockdale Shales. Skelgill Beds. Zone of *Dimorphograptus confertus*.	Skelgill Beds. Zone of *M. fimbriatus*.	Skelgill Beds. Zone of *M. argenteus*.	Skelgill Beds. Zone of *M. convolutus*.	Skelgill Beds. Zone of *M. Clingani*.	Skelgill Beds. Zone of *M. spinigerus*–*Sedgwickii*.	Browgill Beds. Zone of *Rastrites maximus*.	Browgill Beds. Zone of *M. turriculatus*.	Browgill Beds. Zone of *M. crispus*.	Brathay Flags. Zone of *C. Murchisoni*.	S. Scotland. Birkhill Shales, Llandovery. Lower Birkhill. Zone of *D. vesiculosus*.	Lower Birkhill. Zone of *M. gregarius*.	Upper Birkhill. Zone of *Cephalograptus cometa*.	Upper Birkhill. Zone of *M. Sedgwickii*.	Upper Birkhill. Zone of *Rastrites maximus*.	Gala or Tarannon Group. Lower Gala. Abbotsford Flags.	Lower Gala. Gala Grits and Buckholm Sandstones.	Upper Gala. Grieston Beds.	Wenlock. Riccarton Beds. Zones of *C. Murchisoni* & *M. riccartonensis*.
Monograptus riccartonensis, Lapw.																			×
Cyrtograptus Murchisoni, Carr.										×									×
,, *Lapworthi*, Tullb.																			
Monograptus continens, Törnq.																			
,, *vomerinus*, Nich.										×									×
,, *Linnarssoni*, Tullb.																			
,, *(Cyrtograptus) spiralis*, Tullb.																			
,, *speciosus*, Tullb.																			
,, cf. *nodifer*, Törnq.																			
Retiolites Geinitzianus, Barr.									×	×								×	×
Monograptus crenulatus, Törnq.																			
,, cf. *dextrorsus*, Linnr.																			
,, *griestonensis*, Nicol									×									×	
,, *discus*, Törnq.									×								×	×	
,, *crispus*, Lapw.									×							×	×		
,, *exiguus*, Nich.									×							×	×		
,, cf. *densus*, Perner																			
,, *proteus*, Barr.				×												×	×		
,, *runcinatus*, Lapw., mut.																			
Retiolites cf. *obesus*, Lapw.								×								×	×		
Monograptus Marri, Perner																			
,, *priodon*, Bronn										×						×	×	×	×
,, *involutus* (?) Lapw.			×	×											×				
Rastrites hybridus, Lapw.			×	×	×	×							r	C					
Petalograptus palmeus, var. *tenuis*, Barr.									×						×	×	×		
Monograptus nudus, Lapw.																×		×	
,, *gemmatus*, Barr.			×	×															
Rastrites Linnæi, Barr.																×			
,, *maximus*, Carr.							×								C	×			
Petalograptus palmeus, Barr., var.																			
Monograptus subconicus, Törnq.									×						r	×	×	×	
,, *turriculatus*, Barr.								×							r	×	×		
,, *Becki*, Barr.															C	×	×		
Dendrograptus sp.																			
Climacograptus extremus, H. Lapw.																			
Monograptus runcinatus, Lapw.															f	×			
,, *jaculum*, Lapw.					×	×	×							C	f				
,, *Halli*, Barr.						×								r	C	×			
,, *galaensis*, Lapw., mut.														×	×				
,, *distans*, Portl.					×	×								×					
,, *Clingani*, Carr.			×	×	×									r					
,, *Sedgwickii*, Portl.					×	×								C	r	×	×		
,, *discretus*, Nich.					×	×								C					
,, *limatulus*, Törnq.																			
,, *crenularis*, Lapw.			×	×	×								C						
Rastrites peregrinus, Barr.		×	×	×								C	r						
Monograptus cf. *decipiens* (?) Törnq.																			
Petalograptus palmeus, Barr.						×			×			f	f	f	f				
Monograptus harpago, Törnq.																			
Diplograptus sinuatus, Nich.	×	×	×	×	×								f	f	f				
Monograptus communis, Lapw., mut.				×								C							
,, *convolutus*, His.			×	×								r							
,, *nuntius*, Barr.																			
Petalograptus ovato-elongatus, Kurck.		×										×	×	×	×				
Cephalograptus petalum, Elles												×							
,, *bellulus*, Törnq.																			
Monograptus attenuatus (?) Hopk.	×	×	×	×							r	r	r	r	r				
,, *leptotheca*, Lapw.	×	×	×	×		×						r	r						
Diplograptus tamariscus, Nich.		×	×	×	×	×						C	f	f	f	×			
Monograptus regularis, Törnq.																			
,, *gregarius*, Lapw.		×	×	×	×							C	r						
Petalograptus minor, Elles												C							
Monograptus triangulatus, His.		×										f							
Diplograptus magnus, H. Lapw.																			
,, *parvulus*, H. Lapw. (?)																			
Monograptus fimbriatus, Nich.		×										r							
Climacograptus Hughesi, Nich.		×	×	×		×						f	f	f	f				
,, *rectangularis*, M'Coy												f							
Monograptus tenuis, Portl.	×	×	×								r	C	f	f	f				
Climacograptus medius, Törnq.																			
Dimorphograptus Swanstoni, Lapw.	×										r								
Diplograptus vesiculosus, Nich.	×	×									C	r							
Climacograptus scalaris, His.	×	×	×	×	×	×					C	C	f	f	f	×			

SWEDEN (SCANIA). — BOHEMIA.

Species	Sweden. Rastrites-Skiffer. Zone of *M.* cf. *cyphus*.	Zone of *M. triangulatus*.	Zone of *Diplograptus folium*.	Zone of *D. cometa*.	Zone of *M. Sedgwickii*.	Zone of *M. runcinatus*.	Transition-Zone.	Cyrtograptus-Skiffer. Zone of *Cyrtograptus Grayi*.	Zone of *C. spiralis*.	Zone of *C. Lapworthi*.	Zone of *C. Murchisoni*.	Bohemia. Llandovery. *R.-peregrinus* Shales.	Tarannon. Zone of *Rastrites Linnæi*.	Wenlock. Zone of *C. Murchisoni*.
Monograptus riccartonensis, Lapw.														
Cyrtograptus Murchisoni, Carr.											×			×
,, *Lapworthi*, Tullb.										×				
Monograptus continens, Törnq.														
,, *vomerinus*, Nich.											×			×
,, *Linnarssoni*, Tullb.										×				
,, *(Cyrtograptus) spiralis*, Tullb.									×					
,, *speciosus*, Tullb.										×	×			
,, cf. *nodifer*, Törnq.									×					
Retiolites Geinitzianus, Barr.							×	×	×	×	×			×
Monograptus crenulatus, Törnq.								×	×	×				×
,, cf. *dextrorsus*, Linnr.														
,, *griestonensis*, Nicol														
,, *discus*, Törnq.						×	×							
,, *crispus*, Lapw.														
,, *exiguus*, Nich.						×								
,, cf. *densus*, Perner													×	
,, *proteus*, Barr.						×							×	
,, *runcinatus*, Lapw., mut.														
Retiolites cf. *obesus*, Lapw.														
Monograptus Marri, Perner													×	
,, *priodon*, Bronn						×	×	×	×	×	×		×	×
,, *involutus* (?) Lapw.														
Rastrites hybridus, Lapw.														
Petalograptus palmeus, var. *tenuis*, Barr.							×						×	
Monograptus nudus, Lapw.						×	?	×	×	×				
,, *gemmatus*, Barr.													×	
Rastrites Linnæi, Barr.													×	
,, *maximus*, Carr.														
Petalograptus palmeus, Barr., var.														
Monograptus subconicus, Törnq.						×	×	×	?	×				
,, *turriculatus*, Barr.						×							×	
,, *Becki*, Barr.													×	
Dendrograptus sp.														
Climacograptus extremus, H. Lapw.														
Monograptus runcinatus, Lapw.						×							×	
,, *jaculum*, Lapw.					×								×	
,, *Halli*, Barr.													×	
,, *galaensis*, Lapw., mut.														
,, *distans*, Portl.												×		
,, *Clingani*, Carr.												×		
,, *Sedgwickii*, Portl.					×							×		
,, *discretus*, Nich.					×									
,, *limatulus*, Törnq.				×								×		
,, *crenularis*, Lapw.														
Rastrites peregrinus, Barr.												×		
Monograptus cf. *decipiens* (?) Törnq.				×										
Petalograptus palmeus, Barr.		×	×									×		
Monograptus harpago, Törnq.				×										
Diplograptus sinuatus, Nich.												×		
Monograptus communis, Lapw., mut.												×		
,, *convolutus*, His.			×	×								×		
,, *nuntius*, Barr.													×	
Petalograptus ovato-elongatus, Kurck.														
Cephalograptus petalum, Elles														
,, *bellulus*, Törnq.			×	×								×		
Monograptus attenuatus (?) Hopk.														
,, *leptotheca*, Lapw.			×									×		
Diplograptus tamariscus, Nich.	×	×	×	×								×		
Monograptus regularis, Törnq.		?	×	×										
,, *gregarius*, Lapw.		×												
Petalograptus minor, Elles				×										
Monograptus triangulatus, His.		×										×		
Diplograptus magnus, H. Lapw.														
,, *parvulus*, H. Lapw. (?)														
Monograptus fimbriatus, Nich.														
Climacograptus Hughesi, Nich.	×	×	×	×										
,, *rectangularis*, M'Coy	×	×												
Monograptus tenuis, Portl.		?												
Climacograptus medius, Törnq.	×	×												
Dimorphograptus Swanstoni, Lapw.	×													
Diplograptus vesiculosus, Nich.												×		
Climacograptus scalaris, His.			×	×								×		

[Quart. Journ. Geol. Soc. Vol. LXII, Nov. 1906.

TABLE III.—CORRELATION OF THE TARANNON ROCKS.

Tarannon District.	Moffat.	Girvan.	Rhayader.	Lake District.
WENLOCK SERIES.	RICCARTON BEDS.	DAILLY SERIES.		
2. **Fynyddog Grits.**		(*d*) **Straiton Group.** 3. Straiton Grits.		
1. **Nant-ysgollon Shales.**		2. Knockgardner Shales.		
Zone of *M. riccartonensis.* Zone of *C. Murchisoni.*	Zone of *M. riccartonensis.* Zone of *C. Murchisoni.*	1. Blair Flags and Shales.		
TARANNON SERIES.	GALA OR QUEENSBERRY GROUP.			BROWGILL BEDS.
		(*c*) **Drumyork Group.**		
4. **Dolgau Group.** Zone of *M. crenulatus.*	**Upper Hawick Beds.**	(*b*) **Bargany Group.**		**Upper Browgill Beds.**
3. **Talerddig Group.** Zone of *M. griestonensis.*	**Grieston Beds.** With *M. griestonensis.*	(*a*) **Penkill Group.** (4) *Cyrtograptus - Grayi* Mudstones.		
2. **Gelli Group.** Zone of *M. crispus.*	**Buckholm & Gala Grits.** With *M. crispus* and *M. exiguus.*	(3) *Protovirgularia*-Grits.	**Rhayader Pale Shales.** With *M. crispus*, etc.	**Lower Browgill Beds.** Zone of *M. crispus.*
		(2) Penkill Flags and Shales. With *M. exiguus* etc.		
1. **Brynmair Group.** Zone of *M. turriculatus.* With *R. maximus.*	**Abbotsford Flags.** With *M. exiguus*; *M. turriculatus*; *R. maximus.*	(1) *Crossopodia*-Shales.	With *M. turriculatus*, etc.	Zone of *M. turriculatus.*
LLANDOVERY SERIES.	BIRKHILL SHALES.	NEWLANDS SERIES.	LLANDOVERY SERIES.	SKELGILL BEDS.
	(Zone of *R. maximus.*)	(*c*) **Camregan Group.** (With *R. maximus.*)		(Zone of *R. maximus.*)
3. **Twymyn Group.** Zone of *M. Sedgwickii.* Zone of *Cephalograptus cometa.*	Zone of *M. Sedgwickii.* Zone of *C. cometa.*	(*b*) **Saugh-Hill Group.** *M. Sedgwickii*-Beds.	**Caban Group.** 2. Gafallt Beds. With *M. Sedgwickii.*	Zone of *M. Sedgwickii.*
			1. Caban Conglomerates.	Zone of *M. Clingani.*
2. **Dolgadfan Group.**			**Gwastaden Group.**	
Zone of *M. convolutus.*		Woodland	4. Gigrin Mudstones. Zone of *M. convolutus.*	Zone of *M. convolutus.*
	Zone of *M. gregarius.*	and		Zone of *M. argenteus.*
Zone of *M. fimbriatus.*		Glenshalloch Shales.	3. Ddol Shales. Zone of *M. fimbriatus.*	Zone of *M. fimbriatus.*
1. **Fachdre Group.** Zone of *Dimorphograptus Swanstoni.*			Zone of *M. cyphus.* Zone of *M. tenuis.*	Zone of *Dimorphograptus confertus.*
	Zone of *D. vesiculosus.*		2. Dyffryn Flags.	
	Zone of *D. acuminatus.*	(*a*) **Mulloch-Hill Group.** Glenwells Pale Shales. Mulloch-Hill Sandstone. Mulloch-Hill Grit.	1. Cerig - Gwynion Grits.	Zone of *Diplograptus acuminatus.*

The Dolgadfan Beds are represented in the Tarannon District by two zones, namely, those of *Monograptus fimbriatus* and *M. convolutus*. These correspond collectively to Prof. Lapworth's single zone of *M. gregarius* of the Birkhill Shales. That zone contains a rich and varied fauna, and subsequent work[1] has shown the possibility of dividing it into at least three distinct sub-zones, of which *M. fimbriatus* is practically the lowest.

The assemblage of species met with in the Dolgadfan zone of *M. convolutus* corresponds to that of the upper part of Prof. Lapworth's zone of *M. gregarius*. This zone has been detected at two different localities in the Twymyn Valley near Dolgadfan, and the species vary considerably at the two spots. In its lowest band, the zone-fossil itself is rare and *M. leptotheca* and *M.* cf. *decipiens* are the abundant forms; while in its upper band these two species appear to be absent, or at any rate are very rare, and a form which finds its nearest ally in *M. communis* is the most prevalent species.

The two zones of the Twymyn Beds, namely those of *Cephalograptus cometa* and *Monograptus Sedgwickii*, can be exactly paralleled with the corresponding zones in the Upper Birkhill Shales of the South of Scotland. The zone-fossil of the '*cometa*'-band has not been detected as yet in the Tarannon district, but it is always a rare form. The graptolites found in the local zone of *M. Sedgwickii* are typical of that zone wherever it has been recognized. In its lowest beds, *M. Sedgwickii* and *M. discretus* occur almost to the exclusion of other species; while in the upper part new species characteristic of still higher horizons begin to make their appearance.

Thus, in the Llandovery Series of the Tarannon district, which underlies conformably the Tarannon Series, we have the undoubted representatives of all the Lower, Middle, and Upper Birkhill zones with the exception of the lowest (*Diplograptus acuminatus*) and the highest (*Rastrites maximus*). The former is not laid bare in this district, and the latter will be referred to subsequently.

Turning now to the Tarannon Series, we find that in this district it has been possible to distinguish four local zones, namely, those of *Monograptus turriculatus*, *M. crispus*, *M. griestonensis*, and *M. crenulatus*. Some of these have been already recognized elsewhere (p. 696); and as our knowledge of the distribution of the graptolites increases, it is possible that these zones may be found to have more than a local application.

A close comparison between the Tarannon Series as a whole, and the Lower and Upper Gala Beds of the South of Scotland can be instituted, if the zone of *Rastrites maximus* is included. It is true that out of the 38 species found in this district, only 18 have been recorded from the South of Scotland; but of this total of 38 no less than 13 are forms unknown when the Scottish beds were zoned, and the comparison would be far closer if revised lists of the Scottish graptolites were taken instead of the published lists.

[1] J. E. Marr & H. A. Nicholson, Quart. Journ. Geol. Soc. vol. xliv (1888) p. 654; and H. Lapworth, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 67.

The lowest graptolitiferous band in the Brynmair Beds (zone of *Monograptus turriculatus*) is that containing *Rastrites maximus*. This has only been detected with certainty at one locality, and has there yielded nine species. Of this total six occur in the zone of *R. maximus* in the South of Scotland and six in the Lower Gala Beds. Considering now this fauna in the Tarannon district, it is found that only *R. maximus* itself is restricted to this band, the remaining eight species occurring in the succeeding beds of the Brynmair Group. Only one species—*Monograptus Halli*—has at present been detected in the underlying '*M.-Sedgwickii*' Beds, although *M. runcinatus* and *M. jaculum*, which occur in both the *M.-Sedgwickii* and *M.-turriculatus* Beds, will probably be detected in the intervening *R.-maximus* band. If we include in this band the species collected from the bed in the upper part of the Twymyn Valley (p. 688), at the base of the Brynmair Group, the abrupt change in fauna is less conspicuous; but even in this case the palæontological break between the '*Sedgwickii*'- and '*maximus*'-beds is far more marked than it is between the '*maximus*'-band and the rest of the Brynmair Group. At any rate, it is clear that in the Tarannon district the band with *Rastrites maximus* must fall into line with the remainder of the Brynmair Beds, and is hardly worthy of differentiation as a distinct band.

The fauna of the Brynmair Group, as a whole, varies considerably between its lowest and its highest limits, and additional work might lead to further zoning, but our knowledge is at present insufficient. *Monograptus turriculatus* occurs throughout the group, but is most abundant in the lower beds, where it is generally associated with *M. runcinatus*, *M. Becki*, and *Rastrites Linnæi*. The higher beds are apparently characterized by the presence of *Monograptus proteus* and a form which is best compared with *M. densus*, Perner; while *M. exiguus* does not make its appearance until the higher beds. Of the total of 27 species found in the Brynmair Beds, 14 occur in the Lower Gala of the South of Scotland, and the comparison is again still closer if we include new species. There can be no doubt, therefore, that the Brynmair Group corresponds to part, at any rate, of the Lower Gala Beds and the zone of *Rastrites maximus*.

As regards the Gelli Group, an examination of the lists shows that out of its eleven species, six occur in the Lower Gala Beds, and four in the Upper Gala. Thus, these beds have on the whole affinities with the Lower Gala, rather than with the Upper, especially as the characteristic graptolite of the Gelli Group—namely, *Monograptus crispus*—is confined to the Lower Gala Beds. Hitherto *M. exiguus* has been regarded as the zone-fossil of this horizon, but in the Tarannon district this species is not so restricted in range as *M. crispus*, and this latter has therefore been selected as the local zone-fossil.

A reference merely to the published lists gives but little guidance to the true zonal position occupied by the Talerddig Group. As a matter of fact, however, the species found in these beds are almost identical with those from the Grieston Beds of the South of Scotland,

with the exception of *Retiolites Geinitzianus*, which does not make its appearance in this district until the overlying Dolgau Beds are reached. The Talerddig Grits, therefore, correspond to the Grieston part of the Upper Gala Beds of the South of Scotland.

Neither can the exact position occupied by the Dolgau Beds (or local 'Tarannon Shales' of the Survey) be determined by any reference to published lists, since their characteristic fauna has not been recognized hitherto in the South of Scotland. There is, however, no room for doubt that they represent the highest part of the Upper Gala, for not only are they both overlain immediately by the zone of *Cyrtograptus Murchisoni* (the lowest zone of the Nant-ysgollon Group and Riccarton Shales), but also the fauna is in every respect an intermediate one between that of the Grieston and that of the Riccarton Beds. They probably represent the barren beds coming below the Riccarton Beds in the Hawick country. The exact parallelism of the Tarannon Series of this district with the Gala Beds of the South of Scotland (including the zone of *Rastrites maximus*) is thus conclusively proved.

It is hardly necessary to insist on the identity of the fauna of the lower Nant-ysgollon Shales with that of the lowest Riccarton Beds; the presence in both of the characteristic fossil—*Cyrtograptus Murchisoni*—places this beyond dispute. Further work will doubtless show that the upper part of the Nant-ysgollon Shales corresponds to the zone of *Monograptus riccartonensis*, thus completing the parallelism between these shales and the lower part of the Riccarton Group.

It will be unnecessary to compare in detail the three Series of this district with the corresponding beds of Girvan and Bohemia: an examination of the lists in Tables I & II (facing p. 692) will suffice. Reference must be made, however, to the deposits described from the Rhayader district and Conway in Wales, the Lake District, and Scania, where the beds intervening between the Llandovery and Wenlock formations have been carefully zoned.

The district of Rhayader has been worked in greater detail and more recently than any other Llandovery area in Britain: therefore, a more accurate comparison of its graptolitic zones with those in the Tarannon district is rendered possible.

The Fachdre and Dolgadfan Groups correspond to the Gwastaden Group of Dr. Herbert Lapworth in the Rhayader district, although his lowest zones are not exposed in the Tarannon country. The local zone of *Dimorphograptus Swanstoni* can be paralleled generally with his zone of *Monograptus tenuis*; while that of *M. fimbriatus* finds its equivalent in his zone of the same name. Intervening between these two zones, however, there comes in the Rhayader district the zone of *M. cyphus*. The fauna characteristic of this fossiliferous band has not been recognized in the Tarannon district, thus accounting for the abrupt change in fauna observed between the Fachdre and the Dolgadfan Beds. The '*cyphus*'-beds are either faulted out in the Pennant area, or have hitherto escaped detection.

The assemblage of species found in the lowest band of the '*convolutus*'-zone agrees well with that from the Calcareous-Nodule Beds of the Gigrin Mudstones; while that from the higher band may best be compared with Dr. Herbert Lapworth's succeeding zone of *Monograptus convolutus*.

The Twymyn Beds find their nearest palæontological equivalents in his Caban Group; but the lithological characters of the two groups are so different that a close comparison is impossible.

As to the Rhayader Pale Shales, Dr. Herbert Lapworth has shown conclusively that eighteen out of the nineteen species detected in these beds are identical with those from the Lower Gala Group and *Rastrites-maximus* zone combined of the South of Scotland. We can therefore have no difficulty in paralleling his Rhayader Pale Shales with the lower part, at any rate, of the Tarannon Group. A reference to the lists in Table II (facing p. 692) will show that the graptolites collected by him from the lower part of the Pale Shales, namely in the western area, are very similar to those occurring in the Brynmair Shales; while those obtained by him from the upper part, in the eastern area, agree almost precisely with those from the lower part of the Gelli Beds.

When we compare the graptolitic species found in the so-called 'Tarannon Shales' of Conway, as cited in the list in Table I (facing p. 692), which has lately been revised by Miss Elles and myself in the light of further knowledge, we find that it is possible to draw a close parallel between them and the Brynmair Shales. At Conway *Monograptus crispus* has not been recognized hitherto with certainty; and although *M. exiguus* is a fairly-common species there, it is subordinate in importance to *M. turriculatus*, and therefore the highest part of the Gelli Shales is certainly not represented in the section studied by us. The 'Tarannon Shales' at Conway (which include the band separated off as the zone of *Rastrites maximus*) correspond apparently to only the lower fourth of our Tarannon Series.

An examination of the fossil lists of the Skelgill, Browgill, and Brathay Flags of the Lake District reveals a remarkable agreement between their zones and those of the Tarannon district. It is interesting to note in the Browgill Beds the occurrence of the same two local zones of *Monograptus turriculatus* and *M. crispus*, especially as hitherto the separation of these two zones in the Lake District has not been corroborated elsewhere.

The only graptolitic beds on the Continent with which we need parallel the Tarannon strata are the *Rastrites*-Skiffer and the *Cyrtograptus*-Skiffer of Scania. The *Rastrites*-Skiffer have been divided by Prof. Törnquist into six zones; and the assemblage of species of each of these agrees closely with that of the five zones of our Llandovery Series, and with the lowest of our Tarannon Series (zone of *Monograptus turriculatus*), although the graptolite-species selected for the local zone-fossil is not the same in every case.

Prof. Törnquist's zone of *Monograptus runcinatus* appears to

include not only the Brynmair Shales, but also the Gelli Shales, for *M. runcinatus* and *M. turriculatus* occur in association with *M. exiguus* and *M. discus*; indeed, *M. discus* is said[1] to be the most characteristic species of the zone. It is probable, therefore, that the highest beds of the Birkhill (namely, the zone of *Rastrites maximus*) are absent in Scania.

Intervening between the zones of *M. runcinatus* and *C. Murchisoni* there are in Scania, according to Tullberg, four zones, three of which are characterized by species of *Cyrtograptus*. The number of species hitherto detected in these upper zones in Scania is so small, that it is not easy to institute a very close comparison; but they can be paralleled, in a general way, with our Tarannon zones. His zones of *Cyrtograptus Grayœ* and *C. (Monograptus) spiralis* probably correspond to the Dolgau Mudstones, for *Monograptus crenulatus* is an abundant species in both. The latter zone may be paralleled fairly accurately with the fossiliferous band at the top of the Dolgau Group found in the northern part of the district. If *Cyrtograptus Lapworthi* is merely a young form of *C. Murchisoni*, then, in our opinion, both the zones named after these species should be included in the lower part of the Nant-ysgollon Shales. Therefore, in Scania, the division between the *Rastrites*-Skiffer and the *Cyrtograptus*-Skiffer occurs about the middle of our Tarannon Series.

It will be observed that, in the Tarannon district, the highest zone of the Llandovery Series is that of *Monograptus Sedgwickii*. In his paper on the Moffat Series (1878), Prof. Lapworth distinguished a still higher zone in his Birkhill Group, namely, that of *Rastrites maximus*. In his later paper, 'On the Geological Distribution of the Rhabdophora' (1880), while he groups the Birkhill Shales as a whole with the Llandovery, he points out (p. 200) that

> 'the zone of *Rastrites maximus* must be regarded as the zone of transition into the succeeding formation. Its fauna is essentially a compound of those characteristic of the more strikingly-separated beds above and below. It ought, in all probability, to be regarded as forming the base-line of the Tarannon Group';

and in the Table at the end of that paper (p. 204), he groups the zone of *Rastrites maximus* as the lowest zone of the Tarannon formation.

It has, nevertheless, been the frequent habit of stratigraphists to include the whole of the *R.-maximus* zone with the Llandovery. But, so far as the evidence—stratigraphical and palæontological—goes in the Tarannon district, the beds with *R. maximus* certainly form the base of the Tarannon Series, and the division-line between our Llandovery and Tarannon must be drawn at the top of the zone of *Monograptus Sedgwickii*. This also appears to be the most convenient stratigraphical line at Rhayader and at Conway, and it will probably be found to be generally the case elsewhere.

[1] S. L. Törnquist, 'On the Diplograptidæ & Heteroprionidæ of the Scanian *Rastrites*-Beds' Kongl. Fysiogr. Sällskapets i Lund Handl. vol. viii (1897) p. 2.

(*b*) Lithological.

We have seen that, even within the limits of the Tarannon district, the sediments tend to become more argillaceous, and consequently thinner, as they are followed from the south-east to the north-west; and if we leave the Tarannon area and go some 12 miles farther north, to the neighbourhood of Llan-y-Mawddwy, this change becomes still more marked. In the summer of 1905 Miss Elles and I made a traverse of the strata in this district from rocks with Bala fossils, as exposed in the upper waters of the Afon Dyfi, below Yr Eryr, up to Wenlock Beds at the summit of Carreg-y-big. In the intervening ground, along the course of the Cwm Cerddyn, the Gelli, Talerddig, and Dolgau Groups of the Tarannon Series were found to be present with their characteristic graptolites. The grit-beds of the Talerddig Group, however, are here practically confined to one horizon near the top; and the group, as a whole, is more shaly and thinner than in the Tarannon district. The purple bands in the Dolgau Group above (local 'Tarannon Shales' of the Survey) have here completely disappeared, but the graptolitic black shale-bands at the base are well-marked.

Proceeding now to the extreme northern limit of the Welsh 'Tarannon' belt as mapped at Conway, we find that the collective amount of sediment present has diminished to a still greater extent. It is true that at Conway the upper division of our Tarannon Series has not been recognized, if indeed it is not overlapped by the Wenlock Shale; but it may be expected that the whole of the Tarannon is here dwindling to the restricted development which it has in the Lake District beyond (Browgill Beds), where its collective thickness is only some 200 feet.

Still farther north, however, in the South of Scotland, we find a close parallel to the Tarannon Series as developed in the Tarannon district; for in Girvan the beds referred to the Tarannon-Gala Series are nearly 2000 feet thick, while they are perhaps twice as thick in the central, or Gala and Queensberry parts of the Scottish Uplands.

Thus, the results arrived at in the Tarannon district enable us not only to bring the Welsh development of the Tarannon into line with that of other districts, but also more or less to reconcile the various views which are found in geological literature with respect to the Tarannon as a whole. The Tarannon Series, as here defined, includes all the palæontological zones which have been hitherto assigned to it, and it fills up the whole of the period of time intervening between the Llandovery below and the Wenlock above. It includes the oldest and youngest beds which have been mapped as Tarannon by the Survey in Wales; and, in the Tarannon district, at all events, the thickness of the Series is practically equivalent to its maximum development elsewhere.

In conclusion, I wish to express my thanks to the Council of Birmingham University for a research-scholarship in aid of my work; to Miss Elles, Miss C. Chamberlain, Miss H. Clark, Mr. A. R.

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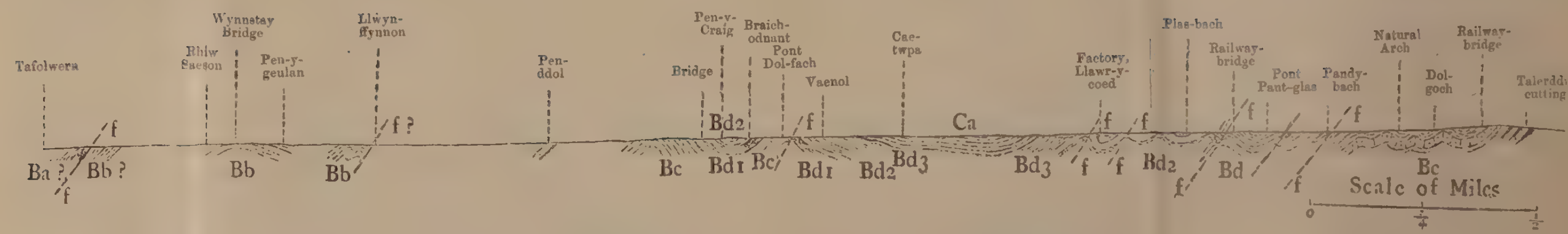
Fig. 1.—*Horizontal section along the Afon Iaen.*



Ca = Nant-ysgollon Shales.

Bd = Dolgau Group { Bd_3 = Upper Green Mudstones. Bd_2 = Middle Purple Sub-group. Bd_1 = Lower Green Sub-group, with black bands. }

Bc = Talerddig Group.
Bb = Gelli Group.
Ba = Brynmair Group.
f f = Faults.

Fig. 2.—*Generalized section from Dolgadfan to Talerddig, across Newydd Fynyddog, on the scale of 3 inches to the mile.*

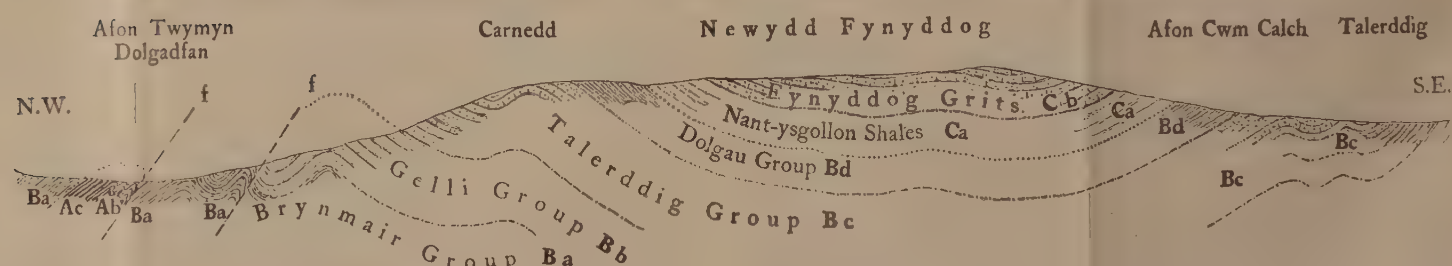
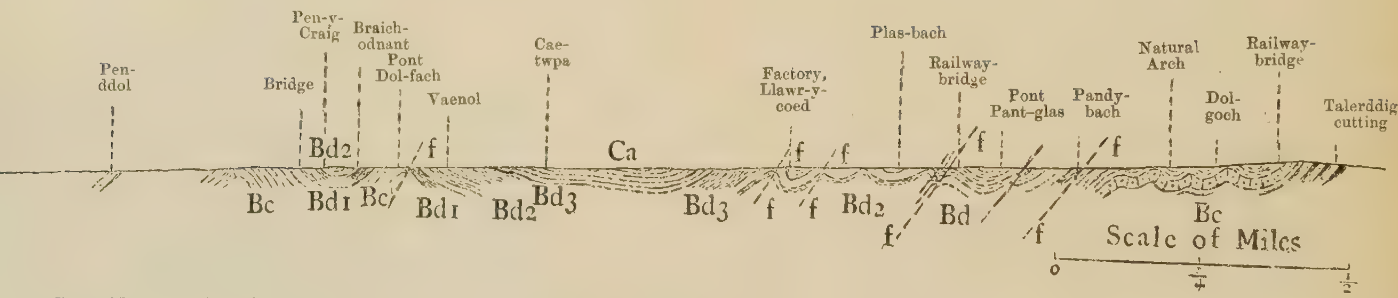


Fig. 1.—*Horizontal section along the Afon Iaen.*



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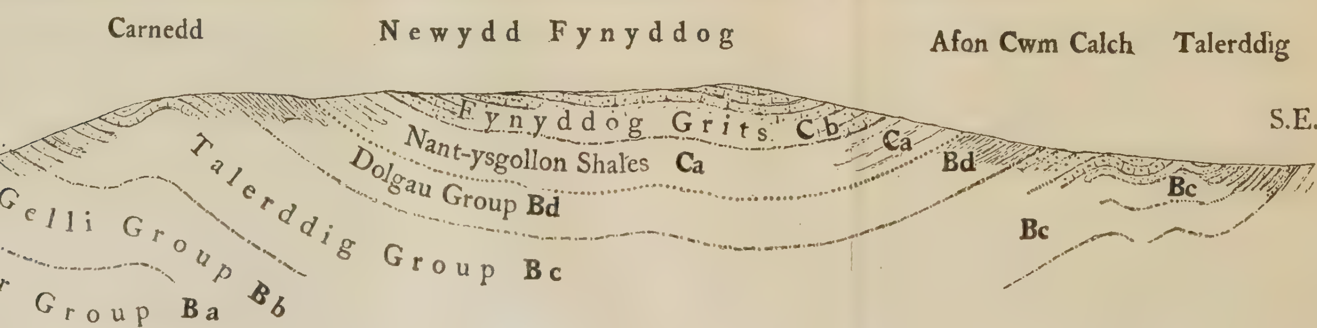

Andrew, and Mr. G. A. Shakespear for help in collecting in the field; and to Dr. Herbert Lapworth for assistance in the identification of some of the more difficult graptolite-forms. Especially do I wish to express my gratitude to Prof. Charles Lapworth, who has assisted me with advice and helpful criticism.

EXPLANATION OF PLATES XLVII & XLVIII.

Plate XLVII.

Geological sketch-map of the Tarannon country, on the scale of 4566 feet to the inch.

Plate XLVIII.

Fig. 1. Horizontal section along the Afon Iaen, on the scale of 3 inches to the mile.

2. Generalized section from Dolgadfan to Talerddig, across Newydd Fynyddog, on the scale of 3 inches to the mile.

Discussion.

The President congratulated the Authoress on the lucid and interesting way in which she had presented her subject to the Society. As an old member of the Geological Survey, he would like to express the satisfaction with which he observed that the subdivision of the Tarannon Shales, first distinguished and mapped on merely-lithological grounds by his friends and colleagues, Jukes and Aveline, had been sustained on palæontological evidence by subsequent observers, and that the original tract of Tarannon, at last so thoroughly worked out, zone by zone, by the Authoress, had been shown by her to contain so full and typical a development of this important group in the Upper Silurian Series of formations.

Dr. Marr said he felt that he might have been mistaken in referring the Cerrig-y-Druidion beds, of which the Authoress had spoken, to the Birkhills; they might well be of Tarannon age. He thought that the *Rastrites-maximus* beds of the Sedbergh district were more closely linked to the Skelgill than to the Browgill Beds. In conclusion, he expressed his high appreciation of the paper.

Mr. Hopkinson said that he had listened to the paper with very great interest, and he was pleased to find the graptolites playing the leading part in so important a communication on the Silurian rocks of Wales. They were proving, as it was anticipated that they would, long before the species had been so well worked out by Miss Elles and the Authoress, invaluable in correlating the rocks of distant areas; and he thought that if the Authoress were to extend her researches into Bohemia, she would find the same succession of species in the rocks from which Barrande obtained the graptolites described by him many years ago.

Prof. Watts, with the President's permission, read the following contribution to the Discussion sent by Dr. Herbert Lapworth:—

'I very much regret that I am not able to be present, but I have been through the manuscript and noted the main points, and was particularly

struck by the remarkable agreement of the results in the Tarannon district with those in the country lying to the south on the southern fringe of the Mid-Wales complex.

'One of the most interesting points, to my mind, is the restriction of the typical brilliant purple mudstones to the upper portion of the Tarannon Shales. In the Rhayader district these bright-coloured rocks are absent. To the east, however, about 12 miles distant from the town of Rhayader, these beds have been mapped by the Geological Survey and traced across country towards the north, where they eventually join the same rocks in the Tarannon district. I visited this eastern district myself about seven years ago, and noted the typical zone-fossil *Monograptus crenulatus* in the purple beds, shown on the Geological-Survey maps. I was never able to understand how this bright-coloured group could cross (apparently unconformably) the typical Pale Shales of the Rhayader district. It now seems perfectly clear, however, that this upper group is entirely absent from the neighbourhood of Rhayader.

'Another point in striking agreement with the same results is the following:— The highest point in the Rhayader district—the summit of the mountain Moel Hywel—does not lie in the older and more arenaceous rocks of the Upper or Lower Llandovery Series, but in the very heart of the softer Rhayader Pale Shales. Nothing is exposed on the summit of the hill; but a pile of grit-blocks in the cairn, and grit-débris lying around, shows that the mountain must be capped by arenaceous rocks. This doubtless corresponds to the base of the Talerddig-Grit group of Tarannon: for, immediately below the summit of this hill, the typical graptolites of the *Monograptus-crispus* zone can be found in the local quarries.

'South of the Rhayader district, in the neighbourhood of New Bridge, only the bright-coloured mudstones are exposed, and have been mapped as Tarannon by the officers of the Geological Survey. The absence of a similar set of beds in the Rhayader district was always puzzling to my mind; but the researches of the Authoress show conclusively that the 'Tarannon' of Rhayader and the 'Tarannon' of New Bridge are not of exactly the same age.

'Another point is the absence of an arenaceous base to the Upper Llandovery Series in the Tarannon district, and it would appear almost as if there were a complete passage upwards from the *Dimorphograptus-Swanstoni* to the *Monograptus-Sedgwickii* Beds. This, however, differs from the succession at Rhayader, where there is a distinct unconformity between the Upper and the Lower Llandovery Groups, with a base to the Upper Llandovery of several hundreds of feet of massive grits and conglomerates. I understand from the paper that the Authoress has not discovered an unconformity; but, as the lower rocks are exposed only in patches, it is quite possible that an unconformity may yet be found.

'As to the inclusion of *Rastrites maximus* with the Tarannon Shales, there is no reason, from the evidence in the Rhayader district at any rate, why this should not be adopted, although I selected *Monograptus exiguus* myself as a suitable fossil for the first Tarannon zone. The Pale Shales of Rhayader commence at the *Rastrites-maximus* Beds, and run on without a break up to the summit of the *Monograptus-crispus* Group: so that, if one adopted the Authoress's suggestion, the Upper Llandovery would be represented by the grits and conglomerates of Caban Côch, and the Rhayader Pale Shales would lie wholly in the Tarannon Series.

'Lastly, the enormous thickness of the Tarannon Series in the Tarannon district will bear out the conclusions already formed with regard to the same rocks at Rhayader, where only the lower half is exposed; and it has been pointed out that the thickness of even this lower half must be very great, for it covers a large area, extending some 12 miles to the north, and about the same distance to the east—altogether not less, probably, than 150 or 200 square miles.

'In conclusion, it gives me great pleasure to be one of the first to congratulate the Authoress on a most interesting and valuable piece of work.'

Mr. W. G. Fearnsides further congratulated the Authoress upon the completion of the fine piece of zonal work described in the

paper. He had had the advantage of being taken over many of the sections by her, and in the field had seen the succession fully demonstrated. He was much impressed by the detailed similarity between the lithological succession of Tarannon with that described by Prof. Lapworth in the central Southern Uplands of Scotland, and suggested that this similarity might be due to the symmetrical position of the two areas on opposite sides of the great Silurian ocean-trough, which, trending north-east and south-west, seems to have been central about some line passing to the south of the Lake District. He noted that, during the Silurian Period, that trough was gradually, but completely, filled with sediment, which was brought in simultaneously from both sides; and that, as time advanced, the flanking belts of greatest sedimentation continuously approached the central deep-water trench. He commented upon the extreme thinness of the Llandovery and Tarannon sediments in Anglesey, Conway, and Criccieth, and thinking that these areas cannot have been far from the centre of the then ocean-trough, enquired whether the supposed break, mapped at the base of the Silurian in North Wales generally, was not due rather to the thinning of the beds than to actual unconformity.

Miss Elles said that she was particularly interested in the upper and lower limits of the Tarannon Series as defined by the Authoress. When working on the Wenlock Shales she had noticed Purple Shales in several places below the lowest Wenlock-Shale zone of *Cyrtograptus Murchisoni*, and she now considered that these should be referred to the Dolgau Group, although possibly the highest members were overlapped in many instances. With regard to the lower limit, she was glad to see that the Authoress definitely included the zone of *Rastrites maximus* in the Tarannon Series, for she had noticed in the South of Scotland that the lithological and faunal change was far more conspicuous below the *R.-maximus* zone than above it, and she had always regarded the inclusion of these beds in the Birkhill Shales as unsatisfactory.

The Authoress thanked the Fellows for the kind reception that they had given to her paper; and, replying to Dr. Marr, said that she had adopted the original suggestion of Prof. Lapworth, that the line between the Llandovery and the Tarannon should be drawn at the top of the zone of *Monograptus Sedgwickii*, partly on palæontological grounds, and partly on account of the constancy and ready detection of that zone in the field. She thought that this classification would prove to have a more than local application, and both at Rhayader and at Conway, at any rate, it seemed advisable on stratigraphical grounds.

30. *On the* IMPORTANCE *of* HALIMEDA *as a* REEF-FORMING ORGANISM: *with a* DESCRIPTION *of the* HALIMEDA-LIMESTONES *of the* NEW HEBRIDES.

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[PLATES XLIX–LI.]

CONTENTS.

I. OCCURRENCE AND CONDITIONS OF GROWTH OF LIVING *HALIMEDA*.

THE importance of *Halimeda* as a reef-forming agent has, until of late years, been greatly overlooked. Many of the earlier records of the occurrence of calcareous seaweeds on coral-reefs were alluded to in a comprehensive manner, as Nullipores and *Lithothamnion*; and, although *Halimeda* was not mentioned, the above terms, convenient but often vague, undoubtedly included growths of that genus.

Prof. A. Agassiz has already recorded the fact that 'immense masses of Nullipores (*Udotea* and *Halimeda*) . . . grow on the shallowest flats' of the Florida reefs.[1]

With regard to the habitat of *Halimeda* in the Laccadives, the following interesting note on *H. opuntia*, Lamx. forma *typica*, by Mr. J. Stanley Gardiner, has been published in a paper by Miss E. S. Barton (Mrs. Gepp)[2]:—

'Rare everywhere on the Minikoi reef; but small masses may be found by searching under stones or in protected situations of the inner part of the reef, near the beach or boulder-zone. In lagoon, not found in currents, but very luxuriant in moderately-still water where it can find any stones to fix itself upon.'

From the dredging operations of Messrs. David, Halligan, & Finckh around the atoll of Funafuti we learn that *Halimeda* is found in the outer slope of the atoll, from a foot or so below sea-level down to about 45 fathoms.[3]

[1] 'Three Cruises of the U.S. Coast & Geodetic-Survey Steamer *Blake*' vol. i (1888) p. 82 (Bull. Mus. Comp. Zool. vol. xiv).
[2] Journ. Linn. Soc. Lond. (Botany) vol. xxxv (1903) p. 476.
[3] 'The Atoll of Funafuti' London, 1904, p. 158.

In the dredgings across the lagoon at Funafuti the variety *macropus* occurred in all the samples, excepting No. 1 (half a mile from the Mission Church), 10 fathoms, where the genus was represented by the type-form.[1]

An interesting note on the rate of growth of *Halimeda* is contributed by Mr. Finckh.[2] A board used as a support for corals in ascertaining their rate of growth had holes bored through it to increase its buoyancy, and through one of these holes a small branch of *Halimeda* was found protruding. After six weeks the *Halimeda* had formed a cluster 55 millimetres high and 80 millimetres in diameter.[3] When dried, this growth represented 14·38 grammes of calcareous matter.

In the New Hebrides, *Halimeda*-joints are a conspicuous feature of the recent calm-water beach-deposits, in positions removed from volcanic interference, and especially where volcanic products are absent. The beach-sands in Vila Harbour are notable examples, *Halimeda* contributing often half of the bulk. The sands from exposed ocean-beaches, where observed, appear to be nearly free from remains of algæ.

II. Previously-recorded Occurrences of accumulated *Halimeda*-Remains other than Recent.

Solomon Islands.

A true *Halimeda*-limestone appears to have been recorded for the first time by Dr. H. B. Guppy. In his description of the calcareous rocks of the Solomon Islands, that author remarks[4] that

'in the composition of such rocks, corals take only a secondary part. In some instances, the rock is composed for the most part of calcareous algæ; in others, again, molluscan shells are conspicuous.'

In a footnote to the foregoing paragraph, Dr. Guppy makes the following interesting observation :—

'A specimen I obtained at Santa Anna was entirely composed of the joints of "*Halimeda opuntia*" which commonly occur in the soundings off coral-reefs.'

The *Halimeda*-limestone, referred to above, evidently occurred in the upraised reef of the elevated island of Santa Anna, described by Dr. Guppy in the before-mentioned work at p. 70.

Christmas Island (Indian Ocean).

In the description of the older Tertiary limestones and upraised reefs of Christmas Island, by Prof. T. Rupert Jones and one of the present writers,[5] reference is made to the occurrence of rocks con-

[1] Journ. Linn. Soc. Lond. (Botany) vol. xxxiv (1900) p. 481.
[2] 'The Atoll of Funafuti' 1904, p. 146. [3] *Ibid.* p. 180.
[4] 'The Solomon Islands: their Geology, General Features, & Suitability for Colonization' London, 1887, p. 74.
[5] 'A Monograph of Christmas Island' London, 1900. See especially pp. 250, 257–64, and also p. 289.

taining, in more or less abundance, the joints of *Halimeda*. No. 963 (blocks from High Cliff, Flying-Fish Cove) contained *Halimeda* associated with *Lithothamnion*, and *Lepidocyclina*, together with other foraminifera; the *Lepidocyclina*, however, was in a fragmentary condition, and appeared to be derived. This rock was apparently transitional between the Miocene and the more recent limestone.

Other samples from Christmas Island containing *Halimeda* are No. 935 (*Halimeda*, *Lithothamnion*, and foraminifera); 215 (large *Halimeda*, *Lithothamnion*, foraminifera and polyzoa); 862 (*Halimeda*, *Lithothamnion*, foraminifera, corals, nullipores, echinoids); 403 A (*Halimeda*, *Lithothamnion*, foraminifera, echinoids); 200 (corals, *Halimeda*, *Lithothamnion*, gastropoda, foraminifera); 202 (coral-rock with occasional joints of *Halimeda* and foraminifera); 208 (coral-rock with *Halimeda* and foraminifera); 209 (*Lithothamnion*, *Halimeda*, foraminifera, corals, echinoids, polyzoa); and 1032 (*Lithothamnion*, *Halimeda*, foraminifera, corals, echinoids, polyzoa, lamellibranchs).

The limestone-specimen No. 935 is, from our present standpoint, one of the most interesting of the Christmas-Island rocks yet examined. It occurs on the central plateau at 800 feet above sea-level, in pinnacles projecting from the soil. The rock is a crystalline limestone crowded with *Halimeda* and *Lithothamnion*, and in its general manner of occurrence may be compared with our *Halimeda*-Limestones from the New Hebrides. Of this rock (No. 935) Dr. C. W. Andrews writes as follows [1]:—

'It seems to be a shallow-water rock, such as might well accumulate in a lagoon.'

Funafuti (Ellice Group).

The enormous quantity of *Halimeda* accumulating in the neighbourhood of many of the so-called 'coral-islands,' whether in the lagoon or in the quieter waters of the outer reef-slope, is forcibly brought home to us by the description of the deposits met with at Funafuti. The results of the two borings in the Funafuti lagoon showed the *Halimeda*-'sand' to be at least 80 feet thick in each place [2]; and shallower parts of the lagoon-floor were found by Messrs. David, Halligan, & Finckh to be covered by a luxuriant growth of the same calcareous seaweed.[3]

Evidence such as this shows that the important deposits of calcareous plant-remains accumulating at the present day, can scarcely be paralleled by any deposit laid down in former geological periods excepting, possibly, the limestones of the Alpine Trias which owe their origin to the thallophytes *Diplopora* and *Gyroporella*.

[1] 'A Monograph of Christmas Island' London, 1900, p. 289.

[2] 'The Atoll of Funafuti' p. 162. (The depth of the water is deducted from the figures given in the report quoted.)

[3] *Ibid.* p. 151.

In all the samples of material from the lagoon-boring at Funafuti, as Miss Barton states,[1]

'The *Halimeda*-joints consisted entirely of *H. opuntia* var. *macropus*. The borings down to 132½ feet[2] were still sufficiently well preserved to show the peripheral cells on decalcification, and at 151 feet the large central tubes were still to be recognized; but below that depth, though the form of the joints was retained, there was no cell-substance after treatment with acid.'

In the solid cores of the main boring and the two earlier borings made by Prof. Sollas (1st Expedition) at Funafuti, *Halimeda* is well represented, but only in one place is it so abundant as to form the greater proportion of the rocks, as in our specimens from the New Hebrides.

Dr. G. J. Hinde makes the following remarks on the genus *Halimeda* occurring in the borings at Funafuti[3]:—

'Detached joints of this genus are present in all the borings; in some portions, as, for example, in the Lagoon-boring, for 60 feet below the lagoon-floor they form the greater part of the rock, and between 652–660 feet in the main boring they are the main constituents of the cores. As a rule, their structure is well preserved, so that they are readily recognized in microscopic sections. The specimens in the Lagoon-boring have been determined by Miss Barton (Mrs. Gepp) to belong to *H. opuntia*, Lam. var. *macropus*, Askenasy. According to Mr. Finckh, *Halimeda* is remarkably abundant, both on the present floor of the lagoon and on the ocean-slopes of the reef at Funafuti.'

Fiji and Tonga.

As affording an interesting comparison with rocks formed under much the same conditions as those of the New Hebrides, we here place in a connected form the notes, given in a recent paper by Mr. R. L. Sherlock, of the occurrence of fossil *Halimeda* in the raised reefs of Fiji and Tonga.[4]

Fiji Group.

Mango. –280 feet: Mr. Sherlock records *Halimeda* in a limestone associated with *Lithothamnion*. The other organisms were almost obliterated excepting a doubtful foraminifer, *Gypsina (?)*.

At 298 feet *Halimeda* was abundant, associated with *Lithothamnion*. At 300 feet *Halimeda* was again found, associated with *Lithothamnion* and corals.

Niue (Savage Island).—Between the Tonga and Fiji Groups. Mr. Sherlock found *Halimeda* in all three terraces.

At 53 feet it was abundant, associated with alcyonarian and tunicate-spicules, and *Lithothamnion*. At 70 feet it again occurred,

[1] Journ. Linn. Soc. London (Botany) vol. xxxiv (1900) p. 481.

[2] Measured from the level of low-water spring-tide, deducting 101 feet for the depth of the water to the floor of the lagoon.

[3] 'The Atoll of Funafuti' 1904. p. 331.

[4] 'The Foraminifera & other Organisms in the Raised Reefs of Fiji' Bull. Mus. Comp. Zool. vol. xxxviii (1903) Geol. Ser. vol. v. No. 8, pp. 349–65.

the rock being rich in organisms, including besides *Halimeda*, *Lithothamnion*, gastropoda, echinoid-fragments, and tunicate-spicules.

At 120 feet *Halimeda* was abundant, associated with echinoderms, polyzoa, tunicate-spicules, and *Lithothamnion*. At 190 feet (near the top of the second terrace), *Halimeda* was again abundant, also *Lithothamnion*, gastropoda, polyzoa, echinoid-spines, and many foraminifera.

At 200 feet the limestone contained *Halimeda*, as well as corals, echinoderms, *Lithothamnion*, and an abundance of tunicate-spicules.

Tonga Islands (Friendly Islands).

In the island of Eua, Sherlock found *Halimeda* associated with *Lithothamnion*, gastropoda, and foraminifera, in the third terrace at a height of 250 feet. In his remarks on *Halimeda* in these elevated reefs, Mr. Sherlock (Bull. Mus. Comp. Zool. vol. xxxviii, 1903, p. 362) says that it

'is much less widely distributed (than *Lithothamnion*). It occurs in nine sections, coming from Mango, Niue, and Eua. It is much less stable than *Lithothamnion*, and this may account, to some extent, for its more limited distribution.'

It may be remarked, à propos of this feature of instability, that the disintegration of *Halimeda* under certain conditions may give rise to the fine, impalpable, and microscopically-granular mud so often observed accompanying lagoon-deposits. Evidence for this was afforded by the elevated plateau-limestones of Christmas Island, already mentioned. The same type of mud was also observed by one of us at various levels in the Funafuti main boring.

III. Description of the *Halimeda*-Limestones of the New Hebrides.

Amongst the raised reef-limestones of the New Hebrides, scattered joints of *Halimeda* obtain a wide distribution; on several occasions, the remains (well preserved) were found in association with foraminiferal tests and gastropod-shells, among the basement-grits [1] underlying the actual reef-limestones. Such material might, it is thought, have been transported considerable distances.

Calcareous rocks, formed almost entirely of the remains of *Halimeda*-joints, are represented in three of the islands of the New Hebrides, namely, Malekula, Espiritu Santo, and Efate.[2]

The several examples from these three localities differ considerably from one another in the condition of preservation of the chief organic constitutent *Halimeda*, in the associated smaller organisms,

[1] Composed largely of volcanic glass and mineral particles; described by Mr. C. Hedley as containing mollusca similar to those dredged by him in 15 fathoms of water off the Palm Islands.

[2] See D. Mawson, 'Geology of the New Hebrides,' Proc. Linn. Soc. N. S. W. vol. xxx (1905) pp. 400-84.

and in the nature of the cement. It seems of sufficient interest, therefore, to describe the specimens separately, in both their macro- and microscopic aspects.

Specimen 109.

Boulder projecting from the ground, near track, 100 feet above Bartaleppe, Malekula.

Description of the Rock.—This rock presents a striking appearance, being a cream-coloured limestone, relieved with snow-white patches due to fractured joints of *Halimeda*. This tendency to fracture in *Halimeda* is caused by the imperfect mineralization of the median series of tubes, which allows the joints to separate along the median plane. In structure the rock is slightly cavernous, and in hand-specimens is seen to consist almost wholly of *Halimeda*-remains (Pl. XLIX, fig. 2).

Microscopical details.—A microscopic examination shows this rock to consist of numerous *Halimeda*-joints, the interspaces being filled with a comparatively-coarse pavement of crystalline calcite. Occasionally the *Halimeda*-joints are surrounded by the encrusting foraminifer, *Polytrema planum*. The *Halimeda* is not thoroughly mineralized, although in some instances the tubular structure is encrusted and infilled with deposited calcareous matter. On the whole, the rock is very friable or pulverulent, so that sections have to be prepared with extreme care. The species commonly present is undoubtedly the typical form of *H. opuntia*, Lamx., and the peripheral cells vary in diameter from 40 μ to 54 μ.

The other organisms taking part in the formation of this limestone are,—a branching *Lithothamnion*, the foraminifera *Alveolina* and *Polytrema planum*, and echinoids, represented by spines and plates (Pl. XLIX, fig. 1).

The following bulk-analysis of this rock shows it to be a remarkably-pure limestone :—

H_2O (below 110° C.)	0·31
H_2O (above 110° C.)	0·69
Insol. $+SiO_2$	0·05
$Al_2O_3+Fe_2O_3$ (trace MnO)	0·27
CaO	54·14
MgO	1·00
CO_2	43·24
P_2O_5	0·28
Alkalies	nil
Sulphate	nil
Chloride	nil
Organic matter	nil
	99·98

H_2O (below 110° C.)	0·31
H_2O (above 110° C.)	0·69
Insol. $+SiO_2$	0·05
$Al_2O_3+Fe_2O_3$	0·27
Calcium-carbonate	95·89
Magnesium-carbonate	2·07
Tribasic calcium-phosphate	0·61
Lime (probably mineral combination)	0·09
	99·98

Specimen 111.

From boulders out of the bed of the Atsone River, S. Santo.

Description of the Rock.—A somewhat dark and impure limestone, bluish when freshly fractured, weathering to brown.

The broken surface reveals numerously-scattered joints of *Halimeda*,[1] having a dull earthy appearance, white to buff-coloured. The species of *Halimeda* commonly present in this rock is the typical *H. opuntia*. A few of the joints, however, compare closely with *H. cuneata*, Kuetzing. The calcareous fragments are seen to include also *Lithothamnion*, gastropoda, and a fair number of the discoidal tests of *Orbitolites* (Pl. L, fig. 2).

Microscopical details.—Under the microscope the larger calcareous fragments in this rock are seen to consist mainly of *Halimeda*, with a small proportion of *Lithothamnion*; there are also numerous foraminifera, such as *Miliolina*, *Orbitolites*, *Globigerina*, *Polytrema planum*, and *Amphistegina*; also occasional fragments of polyzoa, gastropoda, worm-tubes, echinoid-fragments, and tunicate-spicules. These organic constitutents are compactly cemented by a fine to coarsely-crystalline calcite-paste, in which are scattered fragments of crystals and brown-glass particles derived from igneous rocks.

Although some examples of this rock show a considerable admixture of foreign débris, other specimens contain a large proportion of *Halimeda*, and furnish good microscope-slides, in which the structure of this seaweed is seen to be excellently preserved (Pl. L, fig. 1).

Specimen 264.

Shepherd's Hill, Vila, Efate.

This *Halimeda*-Limestone forms a band 15 inches thick, interbedded in the reef-material at Shepherd's Hill. It crops out at an elevation of 365 feet on the northern slope. Some of the coral-limestone above this band looks fairly old, so that this *Halimeda*-Limestone is probably older than the more recent raised reefs.

Description of the Rock.—This rock consists almost entirely of *Halimeda*-joints. It is somewhat cavernous, and the surfaces of the joints are coated thinly with a brown earthy encrustation, probably introduced by percolating surface-waters. Thus, only the freshly-fractured rock appears white. A rude parallelism of the flat *Halimeda*-fragments is noticeable, especially when the rock is machine-sliced (Pl. LI, fig. 2). Several continuous fish-vertebræ are embedded in one of the specimens.

Of the three examples now described, the above is the richest in *Halimeda*.

Microscopical details.—The chief component of this rock is *Halimeda*, which appears amber-brown in section, and still clearly shows the internal canals. The rich brown colour of the *Halimeda*-joints is suggestive of partial phosphatization, but the analysis discloses the presence of only an inappreciable amount of phosphoric acid. The *Halimeda*-joints are unusually thick as compared with *H. opuntia*, and they bear a strong resemblance to *H. versatilis*,

[1] The *Halimeda*-remains in this as well as in the following specimens were first referred to *H. opuntia* by Mr. T. Whitelegge, in the Appendix to the 'Geology of the New Hebrides' Proc. Linn. Soc. N. S. W. vol. xxx (1905) p. 479.

Agardh (= *H. macroloba*, Harvey *non* Decne.). The measurements of the peripheral cells also compare more closely with the latter species, as they average 36 μ in diameter.

There are a fair number of gastropoda and some occasional foraminiferal shells. Noteworthy among the latter is a large form of *Carpentaria*, calling to mind *C. rhaphidodendron*, although more depressed in its habit of growth. One of the joints of *Halimeda* is completely surrounded by an encrusting *Gypsina*, like *G. inhærens* (Schultze), but more regular, and with smaller chambers.

The nature of the calcareous cement in this rock is very interesting. Both calcite and aragonite are represented, and are found respectively in optical continuity upon the prismatic or other crystalline structure of the original organisms. Thus the *Halimeda* exhibits a growth or fringe (in sectional view) of acicular aragonite-crystals, as do also the shells of gastropods, while the *Carpentaria* and lamellibranch-shells are coated with calcite. A secondary infilling of the interspaces between the organic particles, where it has taken place, is in the form of a calcitic mosaic. The microscopical appearance of the cementing-material which binds the constituents of the above limestone is comparable in many respects with that seen in fig. 28 of Dr. Cullis's 'Report on the Mineralogical Changes observed in the Cores of the Funafuti Borings.'[1] (Pl. LI, fig. 1.)

The following analysis was made on selected material, not on bulk, as it was desired to arrive at the composition of the *Halimeda*-constituent, uncontaminated by infiltered extraneous matter. The joints were, therefore, separately detached, and carefully scraped free of surface-stain before powdering.

H_2O (below 110° C.)	0·34
H_2O (above 110°)	1·66
Insol. $+SiO_2$	0·06
$Al_2O_3+Fe_2O_3$ (faint trace MnO)	0·44
CaO	54·44
MgO	0·43
CO_2	42·39
P_2O_5	0·25
Alkalies	slight trace
Sulphate	nil
Chloride	nil
Organic matter	nil
	100·01

H_2O (below 110° C.)	0·34
H_2O (above 110° C.)	1·66
Insol. $+SiO_2$	0·06
$Al_2O_3+Fe_2O_3$	0·44
Calcium-carbonate	95·35
Magnesium-carbonate	0·89
Tribasic calcium-phosphate	0·55
Lime (probably mineral combination)	0·72
	100·01

IV. Concluding Observations.

That which apparently detracts from the importance of *Halimeda* as a reef-forming agent is its greater readiness to decay, as compared with *Lithothamnion*, corals, or foraminifera. That this decay is more apparent than real, may be recognized through the observations made by the members of the Funafuti Exploring Expedition. The borings into the lagoon proved that the *Halimeda* retained its

[1] 'The Atoll of Funafuti' 1904, p. 397.

structure on decalcification for a depth of $35\frac{1}{2}$ feet below the floor of the lagoon, and the central tubes were still visible at 50 feet down. If we presume that the conditions for rapid mineralization are favourable, the structure is thereby permanently preserved, and we have examples such as those just described from the New Hebrides. In the lagoon at Funafuti, *Halimeda* was found growing so densely as to be comparable with a turf of green seaweed, while the underlying mass was aptly compared by Prof. Judd with a peat-bog. In the case of both *Halimeda*-accumulation and peat-bog, although disintegration takes place to a certain extent, it may still form a deposit more or less recognizable as due to the agency of the original plants.

Much of the fine powdery limestone associated with coral-reefs, and more especially with upraised coral-islands such as Christmas Island (Indian Ocean), may be primarily due to lagoon or other deposits formed by the agency of *Halimeda*, which under adverse conditions have broken up into a finely-granular or amorphous material, very suitably conditioned for ready alteration by infiltering solutions.

In speaking of the alga-formed limestones of the Trias, Prof. A. C. Seward [1] refers to the obliteration of structure in many limestone-rocks that may have owed their origin to the agency of calcareous seaweeds.

From their stratigraphical association, we conclude that the oldest of the *Halimeda*-Limestones of the New Hebrides, described above, is that from Malekula (109, p. 707), which probably dates back as far as early Pliocene.

EXPLANATION OF PLATES XLIX–LI.

Plate XLIX.

Fig. 1. Thin section of *Halimeda*-Limestone, 100 feet above Bartaleppe, Malekula. × 14. (See p. 707.)

2. *Halimeda*-Limestone, Malekula. Surface of fractured specimen. Natural size. (See p. 707.)

Plate L.

Fig. 1. Thin section of *Halimeda*-Limestone, from boulders out of the bed of the Atsone River, S. Santo. × 14. (See p. 708.)

2. *Halimeda*-Limestone, Atsone River, S. Santo. Fractured surface of rock. Natural size. (See p. 708.)

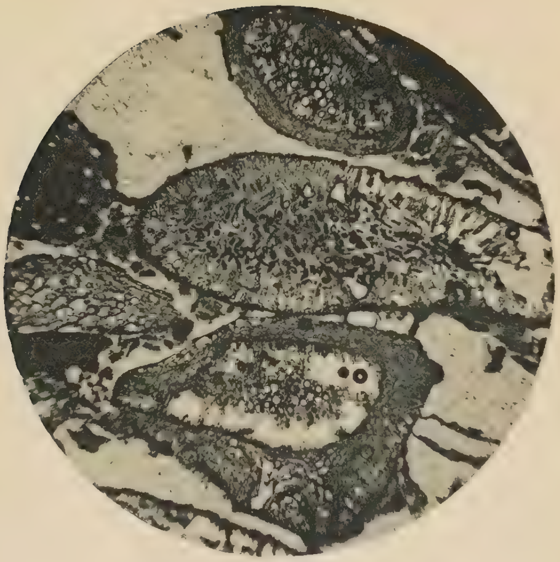
Plate LI.

Fig. 1. Thin section of *Halimeda*-Limestone, Shepherd's Hill, Vila, Efate, New Hebrides. × 14. (See p. 709.)

2. *Halimeda*-Limestone, Shepherd's Hill, Efate. Fractured surface of the limestone, showing its rough, somewhat incoherent texture. Natural size. (See p. 708.)

[1] 'Fossil Plants' vol. i (1898) p. 175.

1



X 14.

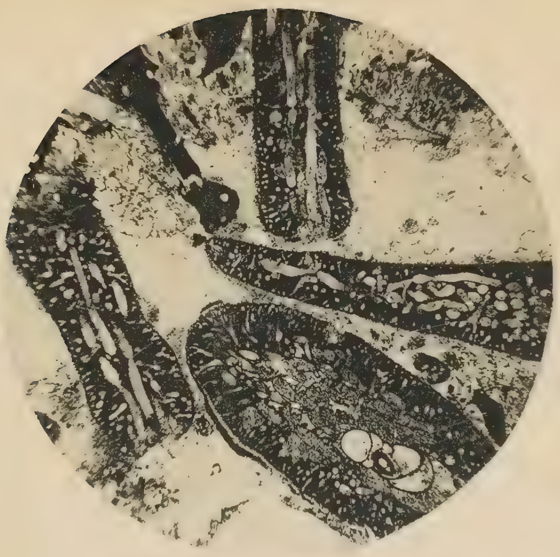
2

Nat. Size.

F. C., Photo. *Bemrose, Collo.*

HALIMEDA–LIMESTONE, MALEKULA (NEW HEBRIDES).

1



X 14.

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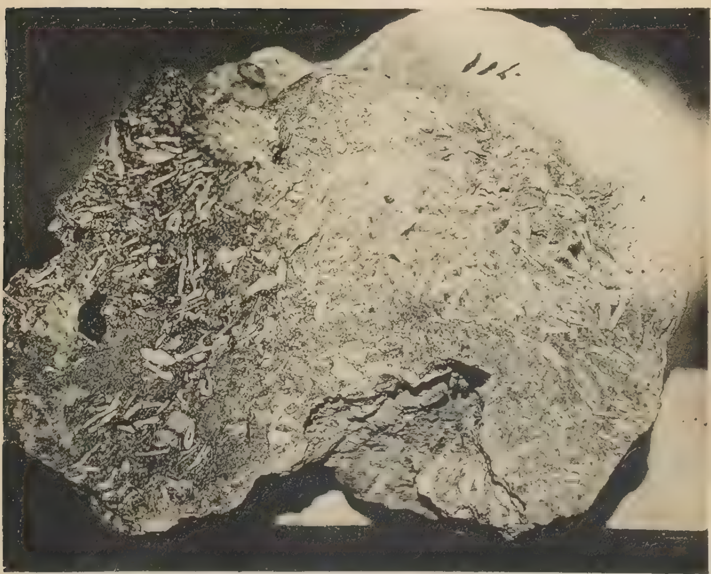


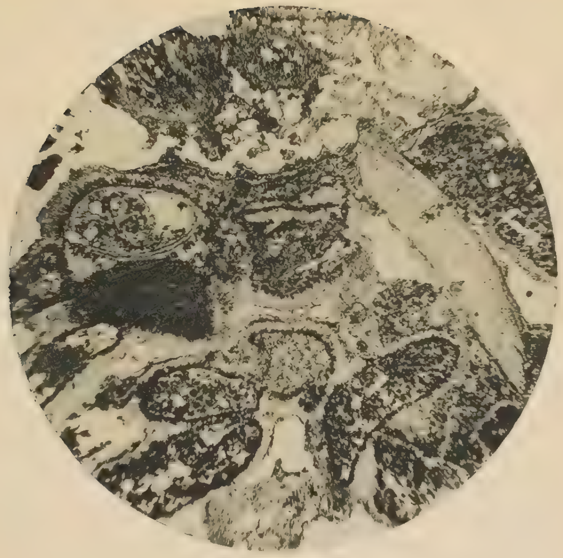
Nat. Size.

F. C., Photo.

Bemrose, Collo

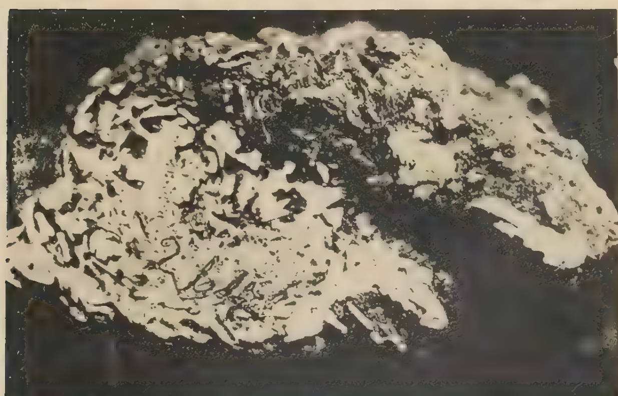
HALIMEDA–LIMESTONE, S. SANTO (NEW HEBRIDES).

1



X 14

2



NAT. SIZE.

F. C., Photo. *Bemrose, Collo.*

HALIMEDA—LIMESTONE, EFATE (NEW HEBRIDES).

Discussion.

The Chairman (Mr. R. S. Herries) called attention to the great interest of the communication, as throwing new light upon the question of the formation of limestones.

Prof. Watts drew attention to the Nullipore-reefs described originally by Sir John Murray. The speaker referred to the 'Richthofen' reefs in the dolomites, and pointed out that the coral-origin of these had been discredited, partly because they contained few corals. The present paper showed that corals might be a very minor contribution to actual 'coral-reefs.'

Prof. Johnston-Lavis said that he wished to draw attention to some papers by Prof. Johannes Walther, in which that investigator expressed the opinion that the calcareous algæ played an important part in the origin of dolomites.

Prof. Judd, replying on behalf of the Authors, stated that the great interest of the paper depended on the circumstance that a calcareous green alga was now shown to play an important part in limestone-building. The freshwater *Chara* and the purple sea-weeds of the type of *Lithothamnion* had long been known to form the basis of limestones. In answer to a question asked by Dr. Robert Bell, he pointed out that, when all structure was destroyed in a limestone by crystallization, its coral-reef origin might be inferred from the smallness of the insoluble residue in this class of rocks. In reply to Prof. Watts, he recalled the important results arrived at by Prof. Skeats in his study of the dolomite-rocks of the Tyrol.

31. *The* CRAG *of* ICELAND — *an* INTERCALATION *in the* BASALT-FORMATION. By Dr. HELGI PJETURSSON. (Communicated by Prof. W. W. WATTS, M.A., M.Sc., F.R.S., Sec.G.S. Read June 13th, 1906.)

THE existence of fossiliferous deposits on the western coast of Tjörnes (Northern Iceland) has been known to science for nearly 160 years. They were first mentioned by the famous Eggert Olafsson in his book entitled 'Enarrationes historicæ de Islandiæ Natura & Constitutione,' etc., published at Copenhagen in 1749.

In 1871 the Danish conchologist O. A. L. Mörch published a paper 'On the Mollusca of the Crag-formation of Iceland,'[1] wherein he enumerated 61 species of molluscs, and arrived at the conclusion that in the Crag-period the temperature of the northern coast of Iceland must have been much milder than now, 'at least as at present on the west coast by Reikiavik' [Reykjavìk], *op. cit.* p. 394.

Some years later, Mr. J. Starkie Gardner collected 33 species of Pliocene molluscs in Iceland, which were studied by Gwyn Jeffreys and Searles V. Wood. In the opinion of Wood, the deposits in question cannot be younger than Middle Red Crag, while Jeffreys thinks that they are somewhat younger. Gardner himself is, however (Quart. Journ. Geol. Soc. vol. xli, 1885, p. 97),

> 'inclined to assign a greater age to the deposit from its general appearance on the spot, than Dr. Gwyn Jeffreys may do, or even than Mr. Searles Wood.'

The most important paper in existence on the fauna of the Icelandic Crag dates from 1884, but only exists in a manuscript, which has been deposited in the archives of the Geological Museum of Copenhagen. It is written by C. M. Poulsen, and is in part founded on the investigations of Mörch. Poulsen, in this MS. — which was kindly lent to me for perusal by Prof. Ussing,—enumerates 117 species of molluscs from the Crag of Tjörnes; out of this number 20 species are new, while of the remaining 97 species 18 per cent. are extinct. Poulsen's somewhat startling conclusion is, that the Crag of Iceland is younger than even the youngest division of the English Crag.

It seems not improbable that the 117 species of molluscs recorded from Tjörnes in 1884 constitute a mixture of different faunas, and possibly the Icelandic Pliocene deposits, which, indeed, are very much thicker than has been generally assumed, fall into several divisions.

Thus Gardner and Poulsen may both of them be in part right. Looking at the percentage of extinct species, it seems not improbable that a portion of the Pliocene fauna of Tjörnes may go farther back

[1] Geol. Mag. vol. viii, p. 391.

than the Red Crag, while, on the other hand, a consideration of the number of Arctic forms makes us believe that perhaps the palæontological evidence of Tjörnes may lead up to the opening scenes of the Pleistocene.

As to the position of the Crag in the Icelandic rock-succession, Prof. Th. Thoroddsen thinks that the Pliocene beds are of later date than the eastern higher part of Tjörnes, which, according to that author, constitutes a projecting remnant of the old basalts ('horst') against which the Pliocene strata are resting.[1] According to Prof. Thoroddsen, the Icelandic Crag 'points to a level of the sea some 150 or 200 feet higher than the existing level.'[2]

The Crag-formation extends along the western coast of Tjörnes for more than 3 miles, forming a fine cliff up to 200 feet in height.

A glance at a topographical map of Iceland will at once show, by the existence of a comparatively-broad bay, what part of the Tjörnes coast is built up by the Pliocene deposits.[3]

It is not my intention here to enter upon a description of the Icelandic Crag, but only to mention a cardinal fact concerning it which has been too long overlooked. Following the Pliocene beds away from the coast up along the stream-courses, we find that, at a height of about 500 feet above the sea, they are overlain by the eastern basalts. The superposition of the basalts upon the fossiliferous series is very clearly seen, and at the contact the underlying sediments are indurated and otherwise altered. We thus find that, far from resting against an older Tertiary 'horst,' the Crag of Tjörnes is older than the eastern basalts, which in Búrfell—part of a denuded Pleistocene volcano—attain a height of 2500 feet.[4]

The Crag of Iceland, then, is a fossiliferous intercalation—exceeding in thickness 500 feet—in the basalt-formation, or rather between the two basalt-formations of Iceland, the Tertiary and the Pleistocene, which are separated by a great gap. Harmonizing with this, we find intercalated among the eastern basalts of Tjörnes indurated ground-moraines with striated stones.

As the majority of naturalists who have visited Iceland have examined the Crag of Tjörnes, it may seem almost incredible that the above-mentioned most important fact for the geology of the country should have remained so long undiscovered. This is, however, easily understood; no one ever doubted the Tertiary age of the rocks that build up the eastern, higher part of Tjörnes; and so investigators spent all the time at their disposal in studying the fine sea-cliff—as, indeed, was the case with myself, on my first visit to Tjörnes.

[1] 'Islandske Fjorde og Bugter' Geograf. Tidsskr. vol. xvi (1901) p. 67.

[2] 'Explorations in Iceland, etc.' Geograph. Journ. vol. xiii (1899) p. 34 sep. cop.

[3] [This has not, however, been remarked by Prof. Thoroddsen, whose map gives a very incorrect idea of the area occupied by the Crag.]

[4] See H. Pjetursson, 'Om Islands Geologi' Copenhagen, 1905, p. 44.

That there is a great unconformity between the two basalt-formations of Iceland is very well seen on the north side of Snæfellsnes (Western Iceland). Here the Pleistocene basalts, together with sedimentary intercalations in the lofty and precipitous Kirkju Fell, have a thickness of more than 1100 feet. The basal part of the fell is built up of decayed basalts, and cut by thick dykes which terminate against the base of the Pleistocene Series. In Stöð and the headland of Búlandshöfði we also find the basal parts cut by thick basalt-dykes; while thinner dykes, having another trend, traverse the Pleistocene formation to the top. In the two last-named localities the basal layer of the Pleistocene Series is fossiliferous, and has, in Búlandshöfði, yielded twenty-two species of mollusca, twenty of which (*teste* Ad. S. Jensen) represent a highly-Arctic fauna (with *Yoldia arctica*), such as at the present day is found living along the coasts of Spitsbergen.

It is a remarkable fact, looking at the very considerable thickness of the Crag of Tjörnes, that nowhere else in Iceland has there been found any trace of such Pliocene deposits. And yet the Pliocene sinking of the land can hardly be supposed to have been confined to the comparatively-limited area which is now Tjörnes.

We shall understand this fact, if we assume that the coast-line of Iceland has receded greatly since Pliocene times—as, indeed, in part can be demonstrated—so that a fringe of Pliocene deposits may have been abraded everywhere, except in a firth cutting exceptionally deep into the country.

Pliocene times would seem to have been, in Iceland, a period of—at any rate comparative—quiescence from vulcanicity. Volcanic accumulation was probably succeeded by subsidence, erosion, and sedimentation. Towards the close of the Pliocene, or at the beginning of the Pleistocene Period, there followed a revival of volcanic energy, which resulted in the building-up of the Pleistocene basalt-formation—a part of which is the palagonite—or 'tuff- and breccia-formation' of the older geologists.

Thus the Pliocene of Tjörnes affords most important complementary evidence as to the age of the much-discussed palagonite-formation. But, even from a more general point of view, the richly-fossiliferous Icelandic Crag is, in my opinion, eminently worthy of the attention of geologists.

I will conclude with the expression of the wish that Science may not have to wait another 20 years for further contributions to the knowledge of the interesting Pliocene fauna of Iceland.

Discussion.

The President referred to this remarkable evidence of the continuity of volcanic activity in Iceland throughout a long interval of geological time. The oldest basalts of that island no doubt dated from some early Tertiary period like those of our own Western Isles. The Crag-deposits noticed in the present paper, as intercalated among the volcanic sheets, furnished interesting and important

evidence of the persistence of the same type of eruptions in later Tertiary time. The occurrence of Glacial deposits between still younger lavas indicated that such eruptions continued during the Ice-Age, while the modern history of Iceland showed that the volcanic activity has persisted up to the present time. Notwithstanding the published writings and the excellent map of Prof. Thoroddsen, and the labours of the Author of the present paper as well as of other observers, much remained to be made known as to the details of this vastly-protracted volcanic history; and all interested in this department of geology must indulge the hope that the subject may be more fully illustrated before many years pass away.

Prof. SOLLAS remarked that the addition of 500 feet,[1] made to the sedimentary series by the discoveries of the Author, involved an addition of 50,000 years to the age of the earth, as calculated from the thickness of the stratified deposits.

[1] [The thickness of the sedimentary series considerably exceeds 500 feet.—*H. P., August 1906.*]

32. Recumbent Folds produced *as a* Result *of* Flow. By William Johnson Sollas, Sc.D., LL.D., F.R.S., F.G.S., Professor of Geology in the University of Oxford. (Read June 13th, 1906.)

Our views as to the various kinds of deformation which affect the earth's crust received a remarkable extension with the memorable discoveries of Lapworth, Peach, and Horne in the north of Sutherland. These have now culminated in the long series of revelations which we owe to Bertrand, Rothpletz, Schardt, Kilian, Haug, Lugeon, Termier, Suess, and other workers in various regions of the Alps, who seem to have accomplished a veritable revolution in this branch of enquiry.

The long recumbent folds, which are perhaps the most surprising of the new forms of disturbance lately brought to light, can be more readily demonstrated than explained.

If we turn to one of the most complete and consistent accounts of these phenomena, Lugeon's description of the pre-Alps of Chablais, we perceive a series of recumbent folds, so greatly exceeding in horizontal extension their thickness vertically, that they are commonly spoken of as sheets rather than folds: they lie with remarkable flatness one on the other; and as a rule those higher in the series extend farther to the front than those below, a feature referred to as 'déferlement' by the French, or 'leap-frog' as translated by my friend, M. Allorge.

The roots or origin of several of the lower of these folds are visible in the high Alps adjacent, but the roots of the higher folds, which form the pre-Alps, must be sought in the zone of Mont Blanc and the Briançonnais. Thus, some of the uppermost folds may have surmounted the obstacle presented by Mont Blanc on their way to the front in the pre-Alps.

It is no doubt true that overfolds may be traced into normal anticlines, and if long recumbent folds may be regarded as merely exaggerated overfolds, we may admit that their origin is not beyond our powers of comprehension; but, even in this case, their subsequent history presents many difficulties to the imagination.

Many of the features presented by recumbent folds are more suggestive of flowing than bending, and long ago this led me to offer a comparison between some of the features presented by the flow-lines in pitch-glaciers with those made familiar to us by the sections of M. Marcel Bertrand.[1] An account of my first experiments with pitch-glaciers was brought before the Geological Society in 1895[2]; but, as no detailed description has been published of others made subsequently, I take this opportunity to present the results of one or two of them, which recall in several striking peculiarities

[1] Rep. Brit. Assoc. 1895 (Ipswich) p. 680.
[2] Quart. Journ. Geol. Soc. vol. li, p. 361

some of the structures brought to light by Prof. Lugeon in the pre-Alps.

In the example that we may consider first (fig. 1, p. 718), the pitch-glacier was built up in the way already described in my previous paper. The three layers, of which the upper surface is indicated by the lines *a*, *b*, *c*, were placed in the experimental trough on April 3rd, 1895; it will be seen that they lie wholly behind the obstacle marked *O*. A fourth layer (*d*) was added on April 9th, its anterior termination lying just upon the summit of the obstacle. The experiment was brought to an end on June 12th, and, on cutting the 'poissier' or pitch-glacier longitudinally through the middle, the layers *a*, *b*, *c* were found to have assumed the forms shown by the lines a', b', c'. The general resemblance between these folded lines and some of the folded sheets in the Alps is sufficiently obvious; the second, marked c', with its 'carapace' of folds is not unlike the Morcles fold behind the Diablerets; and my friend Prof. Lapworth compares the third (b') with the Pilatus and Sentis, and the fourth (a') with the overslide of the Bavarian front.

The roots of the experimental folds lie on the other side of the obstacle *O*, which may be imagined to stand for Mont Blanc. In this respect they recall the views of Prof. Haug, who, to give one instance only, brings the zone of the Aiguilles d'Arve over the summit of Mont Blanc to form the recumbent fold of the Diablerets.

The whole of the four lines exhibit the phenomenon of déferlement, and may be compared in this respect with Prof. Lugeon's illustration of the three folds of Morcles, the Diablerets, and Mont Gond.[1] In the case of the pitch-glacier the déferlement is clearly a necessary consequence of the conditions of the experiment.

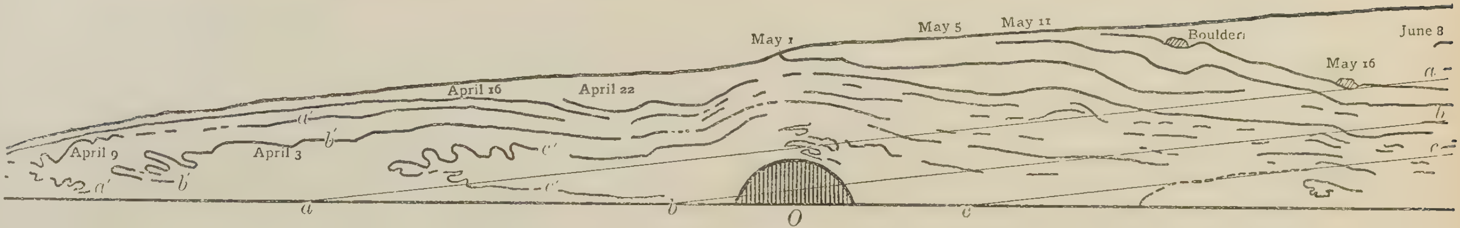
According to our present conceptions, there is one very marked difference which distinguishes the folds exhibited by this pitch-glacier from those of the Alps. In the former, the several folds originate from sheets which were superposed on each other at the commencement of the experiment, and in consequence the lower limb of each fold is adjacent to the similar limb of its neighbours, that is, the folds are 'emboîtés' one in the other. In the mountains, on the other hand, the lower limb of a superior fold reposes on the upper limb of the one immediately beneath it, that is, the folds are superposed, and not fitted one into the other.

In another experiment, however, made between March 24th and June 7th, 1895, even this difference has disappeared, or at least become greatly reduced. In this instance (fig. 2, p. 718), two obstacles O_1 and O_2 were placed in the path of the pitch: restricting our attention to the second layer, the original position of which is shown by the straight line $a\,a'$, it will be seen to have formed three folds one behind the other,[2] all lying on the foreland beyond

[1] 'Les Grandes Nappes de Recouvrement des Alpes du Chablais & de la Suisse' Bull. Soc. Géol. France, ser. 4, vol. i (1901) fig. 3, p. 731.

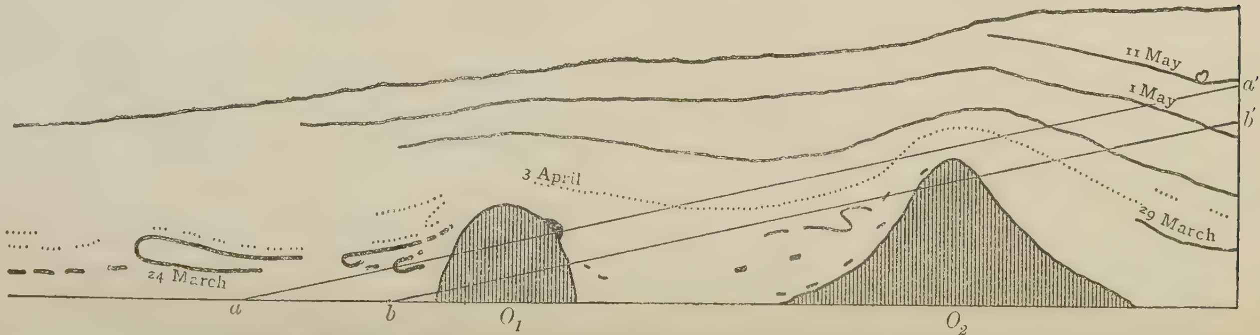
[2] Indicated by the thickened lines, the front fold lies above the words '24 March' in fig. 2.

Fig. 1.—*Experiment commenced on April 3rd, and concluded on June 12th, 1895.*



[$a\,a$ = Original surface at the commencement of the experiment.]

Fig. 2.—*Experiment commenced on March 24th, and concluded on June 7th, 1895.*



[$b\,b'$ = Layer in its original position on March 24th, now seen overfolded immediately above $a\,b$.]

the obstacle O_1, while still farther on are a few scattered fragments, which may be compared with 'klippen.' In this instance, the several lobes of a complex fold would appear to have been sheared away from each other, passing through a series of stages such as are suggested by the folds in fig. 1.

If a flow has taken place in the Alpine regions at all comparable with that of these experiments, it is obvious that particular beds may have been very far from continuous at the conclusion of the movement. Thus, if we regard the layer just referred to as representing a limestone-series in the Alps, we might expect, on leaving the region of the 'klippen,' to enter another of recumbent folds; ascending the mountain-core O_1, we should find on its 'stoss'-side patches of the series, showing obvious signs of excessive pressure; and then we should have to traverse the wide interval between the two crystalline masses O_1 and O_2 before we again encountered insignificant remnants of the original sheet. The absence of the limestone-series between these several points might not, therefore, be the result of denudation, but the natural consequence of mountain-movement. If so, the removal of the stupendous masses of sediment by subaërial agencies, to which the Alps bear such striking witness, is brought closer to our powers of comprehension, since the material thus removed may have been the softer, more mobile argillaceous rock already deprived of its stiffening of comparatively-rigid strata.

Since, in the first experiment, it is only the first four layers that have assumed a complex folded character, and since these were the only layers which were compelled to make a somewhat abrupt ascent on passing over the obstacle O, it would appear probable that the folding stands in some relation to this fact. Such a suggestion is confirmed by reference to the illustration given in my previous paper,[1] where the layers marked 1 and 2, which commenced their existence wholly behind the barrier, have only taken the first step towards surmounting it, by forming comparatively-simple folds. It is in this region then, immediately behind an obstacle, that the production of folds originates, and the reason is clear: the anterior extremity of the layer is in contact, either with the floor of the experimental trough, or with the back of the obstacle, and in these regions the flow of the pitch is greatly retarded or even arrested by adhesion or excessive friction. The layer is held fast at this extremity, and as an upward and forward movement of the pitch takes place immediately behind, the layer is bulged upwards and forwards in the form of a fold. Slight inequalities of friction between the coloured layers of pitch and those to which pigment has not been added, may bring about the formation of secondary folds. In making these comparisons between flowing pitch and mountain-movements, I am anxious not to push the analogy too far; but observation has already so greatly outpaced explanation, that even remote resemblances may possess some value.

[1] Quart. Journ. Geol. Soc. vol. li (1895) fig. 3, p. 364.

Discussion.

The President remarked that it was a source of gratification to the geologists of this country to learn that the types of mountain-structure which were first worked out in detail in the North-West of Scotland had been found so widely distributed over the globe, and that the conclusions regarding them had been so fully accepted by geologists in other lands. Whether or not the extremes to which these conclusions had been pushed by some of the more enthusiastic spirits who had taken them up would ultimately be justified, time must show. In such papers as the present, there always seemed to the speaker to be two distinct, but closely-related aspects of interest. On the one hand, the questions of physical structure possess an absorbing fascination: every year the answers to them are becoming clearer, and our conceptions of the manner in which the crust of the earth has been shaped into its present condition are growing more definite. On the other hand, the solution of these physical problems brings ever into more vivid prominence the stupendous extent to which the surface of our globe has been affected by denudation, and the prodigious length of time during which this slow process of sculpture must have been at work. Even if such gigantic displacements as some observers maintain to have occurred, were eventually found to be somewhat exaggerated, there can be no doubt that the types of mountain-structure which have been proved to exist, while they furnish fresh demonstration of the potency of denudation, supply valuable evidence as to the high antiquity of our globe.

Mr. A. P. Young suggested, in relation to the Author's theory requiring the presence of massive obstacles, that it might be profitable to discuss the hypothesis framed by geodesists to explain the results of pendulum-observations, which require a defect of mass under high mountains.

M. M. Allorge pointed out the close correspondence between the structure of the northern side of the Western Alps and the results of the Author's suggestive experiments. In the central part of the Alps there are two series of elliptical granitic masses, the major axis of which indicates the trend of pre-Permian (Hercynian) folds: the Belledonne zone, and the Pelvoux–Mont-Blanc zone. When the Tertiary overfoldings took place, in consequence of pressures coming chiefly from the south-east, these pre-existing Hercynian horsts were able to play a part similar to that played by the two obstacles of the Author's experiment. They have very likely strengthened the tendency of the folds to form secondary undulations, and to leap one over the other. He considered that the Author's results afforded an experimental verification of the law established by Prof. Lugeon, namely, that the internal folds first produced are the shortest. The most external are the longest, and overlap those which precede them. The difficulties sometimes encountered in attempting to correlate the front of the sheets with their roots are due to the fact that their present separation is not only caused by recent erosion, but some-

times by tectonic disjunctions. He thought that this experiment also gave a good illustration of the structure *en chapelet* of the Alpine geologists; that was, the tendency of the beds of limestone to parcel out into a series of broken segments separated each from the other, recalling on a large scale the dislocated belemnites figured by Prof. Albert Heim in his 'Mechanism of Mountain-building.'

It seemed scarcely necessary to add that plastic movements of such magnitude are only possible at a great depth, and have taken place under a thick covering of Tertiary strata; and perhaps even beneath the background (*rückland* of Prof. Suess) of the Dinarides thrust over the Alpine zone. These external layers have since been swept away by erosion.

The AUTHOR thanked the Fellows for their considerate attention; he was of opinion that some of the folds described by Prof. Lugeon had passed over Mont Blanc.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1905-1906.

November 8th, 1905.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Edwin John Beer, c/o Messrs. Samuel Courtland & Co. Ltd., Foleshill Road, Coventry, and John Shaw Frith, B.Sc., 56 Brocco Bank, Sheffield (Yorkshire), were elected Fellows of the Society.

The President announced that the Council, at their meeting on June 28th last, had passed the following resolutions:—

1. 'The Council desire to record on their Minutes an expression of their deep regret at the death of their distinguished Treasurer, and of their grateful recognition of the loyal and effective services which for so long a series of years he has given to the Geological Society as Secretary, President, Treasurer, and Member of Council.'

2. 'That a copy of this resolution be forwarded to Mrs. Blanford, with an expression of the deep sympathy of the Council with herself and family.'

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Coast-Ledges in the South-West of the Cape Colony.' By Prof. Ernest Hubert Lewis Schwarz, A.R.C.S., F.G.S.

2. 'The Glacial Period in Aberdeenshire and the Southern Border of the Moray Firth.' By Thomas F. Jamieson, F.G.S.

The following photographs and maps were exhibited :—

Photographs exhibited by Prof. E. H. L. Schwarz, A.R.C.S., F.G.S., in illustration of his paper.

Geological Survey of England & Wales :—1-inch Map, n. s. (colour-printed), Sheet 141, Derby, Burton-on-Trent, Loughborough, &c., by C. Fox Strangways & W. W. Watts; Sheet 282, Devizes, by F. J. Bennett & A. J. Jukes-Browne; and Sheet 299, Winchester, by W. Whitaker & C. E. Hawkins.

Geological Survey of Scotland: 1-inch Map, Sheet 55, Blair Atholl, by J. Horne, J. R. Dakyns, G. Barrow, J. S. Grant Wilson, H. M. Cadell, & E. H. Cunningham-Craig.

Geological Survey of Ireland: 1-inch Map. Parts of Sheets 186, 187, 194, & 195, Cork & Cork Harbour (colour-printed), by G. W. Lamplugh, J. R. Kilroe, A. McHenry, H. J. Seymour, W. B. Wright, & H. B. Muff.

All the foregoing maps were presented by the Director of H.M. Geological Survey.

General Map of the Bituminous Coalfields of Pennsylvania, on the scale of 4 miles to the inch, by Baird Halberstadt, presented by the Author.

November 22nd, 1905.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

J. D. Falconer, M.A., B.Sc., Principal of the Mineralogical Survey of Northern Nigeria, Imperial Institute, South Kensington, S.W.; and A. Santer Kennard, 161 Mackenzie Road, Beckenham (Kent), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On a New Specimen of the Chimæroid Fish, *Myriacanthus paradoxus*, Ag., from the Lower Lias of Lyme Regis (Dorset).' By Arthur Smith Woodward, LL.D., F.R.S., F.L.S., F.G.S.

2. 'The Rocks of the Cataracts of the River Madeira and the Adjoining Portions of the Beni and the Mamoré.' By John William Evans, D.Sc., LL.B., F.G.S.

3. 'The Doncaster Earthquake of April 23rd, 1905.' By Charles Davison, Sc.D., F.G.S.

The following specimens and maps were exhibited :—

Myriacanthus paradoxus, Ag., from the Lower Lias of Lyme Regis, exhibited by Dr. A. Smith Woodward, F.R.S., F.L.S., F.G.S., in illustration of his paper.

Specimens, microscopic rock-sections, and lantern-slides, exhibited by Dr. J. W. Evans, LL.B., F.G.S., in illustration of his paper.

Associated set of teeth of *Ptychodus polygyrus* from the *Holaster-subglobosus* Chalk of Holborough, near Rochester, exhibited by G. E. Dibley, F.G.S.

Geologische Karte der im Reichsrathe vertretenen Königreiche und Länder der Œsterreichisch-Ungarischen Monarchie: $\frac{1}{75,000}$. Lieferung VI: N.W. Gruppe, Nos. 40, 65, 75, & S.W. Gruppe, Nos. 19, 98, 110, 120.—1905. Presented by the Director of the Geologische Reichsanstalt.

A Special General Meeting was held at 7.45 o'clock p.m., before the Ordinary General Meeting, at which Horace Woollaston Monckton, Treas.L.S., was elected Treasurer, and Richard Hill Tiddeman, M.A., was elected a Member of Council.

December 6th, 1905.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Ernest Evans Willoughby Berrington, Rosehaugh, Penn, Wolverhampton; Henry Briggs, Assoc.R.S.M., Langcliffe, Scholemoor, Bradford; John C. Brown, B.Sc., Assistant-Superintendent, Geological Survey of India, Calcutta; Tobias Clegg, Assoc.R.C.S., Mona House, Llangefni (Anglesey); Charles James Coleman, 22 St. Mary Axe, E.C.; Hugh Burton Corbin, B.Sc., 52 Bedford Row, W.C.; James Henry Frogley, Assoc.M.Inst.C.E., Lakeside, Bradshaw, Bolton; Glen George, B.Sc., The Laurels, Aberdare (Glamorgan); Arthur Samuel Horne, 6 Fairpark Road, Exeter; Col. Duncan A. Johnston, C.B., R.E., United Service Club, Pall Mall, S.W.; James Victor Burn Murdoch, Neuck, Larbert (Stirlingshire); Frederick Parnell Paul, Ph.D., c/o Messrs. Paul & Gray Ltd., Sussex Street, Sydney (New South Wales); Hubert Francis Gardner Roose, Assoc.R.S.M., c/o the Royal School of Mines, South Kensington, S.W.; and George William Young, 34 Glenthorne Road, Hammersmith, W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Physical History of the Great Pleistocene Lake of Portugal.' By Prof. Edward Hull, LL.D., F.R.S., F.G.S.[1]

2. 'The Geological Structure of the Sgùrr of Eigg.' By Alfred Harker, M.A., F.R.S., F.G.S.

[1] Withdrawn by permission of the Council.

Dr. J. W. Evans, in showing a new method of determining the optic axial angle of a biaxial mineral, by rotating it in parallel polarized light, on an axis at right angles to the optic axial plane and to the axis of the microscope, said that the positions in which the relative retardation was zero corresponded to the optic axes, and the angle between these positions was the optic axial angle in air or in the medium in which the mineral was immersed. To determine when the relative retardation is *nil* the nicols are placed at angles of 45° with the axis of rotation: the double wedge described in the 'Mineralogical Magazine' for May 1905 (vol. xiv, p. 29) is then inserted, and the position noted when the bands on the two halves of the wedge are in exact continuation of one another.

This method is applicable to sections of minerals in rock-slides which are cut at right angles to the optic axial plane; for the observation can be made with a low power, which admits of the slide being freely rotated in a stage-goniometer. With the higher powers which are necessary for microscopic observations in convergent light, a rock-slide could only be rotated within very narrow limits.

Dr. F. A. Bather, in exhibiting fossils from various localities in New Zealand, hitherto known as the Mount-Torlesse Annelid, but described in the 'Geological Magazine' (December 1905) as *Torlessia Mackayi*, a new genus and species of tubicolous Polychæta, and as *Dentalium Huttoni*, sp. nov., explained that, relying on determinations of other fossils by New Zealand geologists, he had supposed the age of the Mount-Torlesse Shales to be not earlier than Carboniferous and not later than Triassic. Prof. James Park, however, had shown that the Maitai Series, with which these rocks were usually correlated, was probably Lower Jurassic (Trans. N. Z. Inst. vol. xxxvi). Since the volume containing Prof. Park's paper had not been received either at the Natural History Museum or at the Science Library, South Kensington, the speaker had been led into the above error, which he desired to take the earliest opportunity of correcting.

In addition to the exhibits described above, the following specimens and maps were exhibited:—

Lantern-slides exhibited by Prof. E. Hull, LL.D., F.R.S., F.G.S., in illustration of his paper.

Specimens of rocks from the Sgùrr of Eigg, photographs (by A. S. Reid, M.A., F.G.S.) and lantern-slides, exhibited by Alfred Harker, M.A., F.R.S., F.G.S., in illustration of his paper.

A weathered pebble from St. Bride's Bay (Pembrokeshire), exhibited by J. V. Elsden, B.Sc., F.G.S.

Geological Survey of England & Wales: 1-inch Map (Drift), n. s., Sheet 283, Andover, by F. J. Bennett & C. E. Hawkins; and

Sheet 284, Basingstoke, by F. J. Bennett, J. H. Blake, & C. E. Hawkins, both colour-printed. Presented by the Director of H.M. Geological Survey.

December 20th, 1905.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Thomas Franklin Sibly, B.Sc., The University, Birmingham, was elected a Fellow; and Prof. Louis Dollo, Curator of the Royal Museum of Natural History, 31 Rue Vautier, Brussels; and Dr. August Rothpletz, Professor of Geology & Palæontology in the University of Munich, were elected Foreign Members of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Highest Silurian Rocks of the Ludlow District.' By Miss Gertrude L. Elles, D.Sc. (Dublin), and Miss I. L. Slater, B.A. (Dublin), Newnham College, Cambridge. (Communicated by Prof. T. McKenny Hughes, M.A., F.R.S., F.G.S.)

2. 'The Carboniferous Rocks at Rush (County Dublin).' By Charles Alfred Matley, D.Sc., F.G.S. With an Account of the Faunal Succession and Correlation, by Arthur Vaughan, B.A., D.Sc., F.G.S.

Prof. G. F. Wright, in exhibiting a map of the Lebanon district, gave an interesting description of the evidence which he found, in a recent journey to that district, as to the height and extent of the terminal moraine. He remarked also that the water-level in the Jordan Valley stood, in comparatively-recent times, 750 feet higher than at present, and this he connected with the glaciation of the area. Very small climatic changes would be sufficient to start the Lebanon Glacier again.

The following specimens and drawings were exhibited:—

Fossils exhibited in illustration of the paper by Miss G. L. Elles, D.Sc., and Miss I. L. Slater, B.A.

Rock-specimens, etc exhibited by Dr. C. A. Matley, F.G.S., in illustration of his and Dr. Vaughan's paper.

Water-colour drawings of microscopic rock-sections by the late Rev. T. Neville Hutchinson, made about the year 1878, exhibited by the Rev. H. Neville Hutchinson, B.A., F.G.S.

January 10th, 1906.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Sydney Edgar Thomas, Mining Engineer, Sydney, Cape Breton (Nova Scotia); and Bristow J. Tully, 23 Antrim Mansions, Hampstead, N.W., were elected Fellows of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—Bedford McNeill, A.R.S.M., and John Smith Flett, M.A., D.Sc.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Clay-with-Flints: its Origin and Distribution.' By Alfred John Jukes-Browne, B.A., F.G.S.

2. 'On Footprints from the Permian of Mansfield (Nottinghamshire).' By George Hickling, B.Sc. (Communicated by Prof. W. Boyd Dawkins, M.A., D.Sc., F.R.S., F.G.S.)

The following specimens, etc. were exhibited:—

Casts and lantern-slides of footprints from the Permian of Mansfield, exhibited in illustration of the paper by George Hickling, B.Sc.

Sheet 37, Inveraray, of the 1-inch map, recently issued by the Geological Survey of Scotland, presented by the Director of H.M. Geological Survey.

January 24th, 1906.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The Secretary announced the donation of the following portraits:—Framed photograph of the late Dr. W. T. Blanford, C.I.E., F.R.S., Treas.G.S., presented by Mrs. Blanford; framed photograph of Prof. J. W. Judd, C.B., LL.D., F.R.S., presented by himself; framed photograph of the late J. P. Lesley, For.Memb.G.S., presented by Sir Archibald Geikie, D.C.L., Sc.D., Sec.R.S.; portrait of Prof. T. McKenny Hughes, M.A., F.R.S., presented by Dr. Henry Woodward, F.R.S.

The following communications were read:—

1. 'On the Igneous and Associated Sedimentary Rocks of Llangynog (Caermarthenshire).' By T. Crosbee Cantrill, B.Sc., and Herbert Henry Thomas, M.A., F.G.S.

2. 'The Buttermere and Ennerdale Granophyre.' By Robert Heron Rastall, B.A., F.G.S. (Christ's College, Cambridge).

The following specimens, etc. were exhibited:—

Rock-specimens, microscope-sections, lantern-slides, and MS. geological 6-inch maps, exhibited by T. C. Cantrill, B.Sc., and H. H. Thomas, M.A., F.G.S., in illustration of their paper.

Rock-specimens and lantern-slides, exhibited by R. H. Rastall, B.A., F.G.S., in illustration of his paper.

Geological Survey of England & Wales: 1-inch map, n. s., Sheet 332, Bognor (Drift), by C. Reid; and Sheet 334, Eastbourne (Drift), by W. A. E. Ussher & C. Reid, both colour-printed; presented by the Director of H.M. Geological Survey.

February 7th, 1906.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Walter Thomas Gillett Burr, Oak Close, Brimington, Chesterfield; and Charles Henry Gott, A.M.I.C.E., F.S.I., 8 Charles Street, Bradford (Yorkshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Carboniferous Limestone (Avonian) of the Mendip Area (Somerset), with especial reference to the Palæontological Sequence.' By Thomas Franklin Sibly, B.Sc., F.G.S.

2. 'The Igneous Rocks of the Eastern Mendips.' By Prof. Sidney Hugh Reynolds, M.A., F.G.S.

The following specimens were exhibited:—

Fossils, rock-specimens, microscope-sections, and lantern-slides, exhibited by Prof. S. H. Reynolds, M.A., F.G.S., in illustration of his paper.

Fossils from the Carboniferous Limestone of the Mendips, exhibited by H. Franklin Parsons, M.D., F.G.S.

ANNUAL GENERAL MEETING,

February 16th, 1906.

J. E. Marr, Sc.D., F.R.S., President, in the Chair.

Report of the Council for 1905.

We regret to have to announce a decrease in the total Number of Fellows, although the Number elected (48) during the year under review exceeded by 2 the Number elected in each of the years 1903 and 1904. Of the 48 Fellows elected in 1905, 36 paid their Admission-Fees before the end of that year, and 13 Fellows, who had been elected in the previous year, also paid their Admission-Fees during 1905. The total Accession of New Fellows within the twelve months under review amounts, therefore, to 49 (the same number as in 1903, but 5 more than in 1904).

Setting against this number a loss of 61 Fellows (26 by death, 19 by resignation, and 16 by removal from the List, under Bye-Laws, Sect. VI, Art. 5), it will be seen that there is a decrease in the Number of Fellows of 12 (as compared with a decrease of 3 in 1904, and of 4 in 1903).

The total Number of Fellows is thus reduced to 1239, made up as follows:—Compounders, 280; Contributing Fellows, 926 (8 less than in 1904, and 4 less than in 1903); and Non-Contributing Fellows, 33.

Turning now to the Lists of Foreign Members and Foreign Correspondents, we have, as in the previous year, to deplore the loss of two of the former, Baron Ferdinand von Richthofen and Prof. Gustave Dewalque, and also the loss of one Foreign Correspondent, Prof. Victor Raulin. The vacancies thus created were in part filled by the transfer of Dr. Louis Dollo and Prof. August Rothpletz from the List of Correspondents to that of Members, and by the election of Prof. Bundjirô Kôtô (the first native of Japan to appear in the List) as Foreign Correspondent. At the end of the year there still remained, however, two vacancies in the List of Foreign Correspondents.

With regard to the Income and Expenditure of the Society during 1905, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—

The total Receipts, including the Balance of £409 7*s*. 7*d*. brought forward from the previous year, amounted to £3371 9*s*. 7*d*., being £25 6*s*. 0*d*. more than the estimated Income.

The total Expenditure during the same period amounted to £3066 6*s.* 10*d.*, being £129 10*s.* 10*d.* more than the estimated Expenditure for the year, and £104 4*s.* 10*d.* in excess of the actual Receipts. The three principal items in regard to which the Expenditure exceeded the sums provided in the Estimates were the Quarterly Journal (excess £34 12*s.* 2*d.*), the Library (excess £44 10*s.* 5*d.*), and Miscellaneous Printing (excess £30 11*s.* 4*d.*).

The Council have to announce the completion of Vol. LXI and the commencement of Vol. LXII of the Society's Quarterly Journal.

Mr. C. Davies Sherborn is making increasingly-rapid progress with his manuscript Card-Catalogue of the Library, and it may now be said that 'the end is in sight.' A considerable number of new cabinets for the purpose of accommodating this Catalogue are provided for in the Estimates for the current year.

Mr. Sherborn having intimated his inability to undertake, after the end of 1905, the preparation of the catalogue-slips for the International Catalogue of Scientific Literature, the Council appointed a Committee to review the part hitherto taken by the Society in furnishing the slips for British Geology to the Central Bureau, and that Committee have recommended the discontinuance of the work under present conditions. The Committee have further recommended that modifications be made in the Society's Record of Geological Literature, so that all geological literature published in Britain shall be included, and that slips from it shall be available for the purposes of the Central Bureau of the International Catalogue of Scientific Literature.

The Committee engaged in the preparation of the Centenary Record of the Society, initiated by Mr. Horace B. Woodward, are able to report that substantial progress towards the completion of the work has been made during the past year.

The lamented decease of Dr. W. T. Blanford, which took place most unexpectedly towards the end of June last, deprived the Council of the aid and advice of one who had for the last 21 years (first as Secretary, from 1884 to 1888; then as President, from 1888 to 1890; and finally as Treasurer, from 1895 until his decease) served the Society with unflagging devotion and zeal. In accordance with the prescriptions of the Charter and Bye-Laws, a Special General Meeting was held on November 22nd, 1905, at which Mr. H. W. Monckton was elected Treasurer, and Mr. R. H. Tiddeman a Member of the Council, to fill the vacancies thus created.

The third Award from the Daniel Pidgeon Trust-Fund was made, on May 10th, 1905, to Mr. Thomas Vipond Barker, B.A., who proposed to investigate the deposition of crystals of minerals and other substances in regular position on each other, with special reference to such groups as those of calcite, barytes, aragonite, etc.

The following Awards of Medals and Funds have also been made by the Council:—

The Wollaston Medal is awarded to Dr. Henry Woodward, F.R.S., in recognition of the value of his 'researches concerning the mineral structure of the Earth,' and particularly of his valuable contri-

butions to the science of Palæontology, more especially to our knowledge of the fossil Arthropoda.

The Murchison Medal, together with a Sum of Ten Guineas from the Murchison Geological Fund, is awarded to Mr. Charles Thomas Clough, M.A., in recognition of his invaluable contributions to Geological Science, by means of the Maps and Memoirs executed by him for H.M. Geological Survey.

The Lyell Medal, together with a Sum of Twenty-Five Pounds from the Lyell Geological Fund, is awarded to Prof. Frank Dawson Adams, Ph.D., 'as a mark of honorary distinction, and as an expression on the part of the Council that he has deserved well of the science,' particularly by his contributions to our knowledge of the geology of Canada.

The Prestwich Medal is awarded to Mr. William Whitaker, F.R.S., as an acknowledgment of the work that he has done for the advancement of the science of Geology, particularly by his researches among the Tertiary strata of the London and Hampshire Basins.

The Balance of the Proceeds of the Wollaston Donation-Fund is awarded to Dr. Finlay Lorimer Kitchin, M.A., as an acknowledgment of the value of his investigations concerning the fossil Brachiopoda, and other Invertebrata, especially in India, and in order to encourage him in further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. Herbert Lapworth, B.Sc., as an acknowledgment of the value of his investigations regarding the Llandovery rocks of the Rhayader district, and as an incentive to further work.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. William George Fearnsides, M.A., in recognition of his valuable contributions to our knowledge of the Lower Palæozoic and the Cretaceous rocks, and in order to encourage him in further investigations.

The other moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Richard H. Solly, M.A., as an acknowledgment of the valuable work done by him on the minerals of the Binnenthal and other districts, and as an encouragement to further research.

A sum of Twenty-Five Pounds from the Barlow-Jameson Fund is awarded to Mr. Henry C. Beasley, in recognition of his important work on the Triassic rocks, and in order to encourage him in further research.

Report of the Library-and-Museum Committee for 1905.

The Additions made to the Library during the Year under review have fully maintained, both in number and in importance, the standard of previous years.

During the past twelve months the Library has received by Donation 200 Volumes of separately-published Works, 318 Pamphlets

and detached Parts of Works, 268 Volumes and 87 detached Parts of Serial Publications, and 20 Volumes of Newspapers.

The total Number of Accessions to the Library by Donation is thus found to amount to 488 Volumes, 318 Pamphlets, and 87 detached Parts. Moreover, 86 Sheets of Geological Maps were presented to the Library. This unusual number of strictly-geological maps included 20 Sheets received from H.M. Geological Survey; 10 Sheets from the Geological Survey of Canada; 11 Sheets from the Russian Geological Survey; 7 Sheets from the Imperial Austro-Hungarian Geological Institute; 5 Sheets of the International Geological Map of Europe; 6 Sheets from the Swiss Geological Commission; 8 Sheets from the Geological Survey of Sweden; 5 from that of Rumania; and 6 from that of Japan. Mr. C. V. Bellamy presented a copy of his Geological Map of Cyprus; Capt. Baird Halberstadt presented a copy of his Map of the Bituminous Coalfields of Pennsylvania; and the late Prof. Gustave Dewalque presented a copy of his Tectonic Map of Belgium and the neighbouring Provinces.

Among the Books and Pamphlets mentioned in the foregoing paragraph, special attention may be directed to the following works:—The 5th Edition of Prof. A. de Lapparent's 'Traité de Géologie'; Part II of Vol. I of the new Edition of Prof. Rosenbusch's 'Mikroskopische Physiographie der Mineralien & Gesteine' (in collaboration with Dr. E. A. Wülfing); Prof. L. de Launay's 'La Science géologique'; Dr. Charles Davison's 'Study of Recent Earthquakes'; the 6th Edition of the late Sir Clement Le Neve Foster's 'Ore & Stone-Mining' (revised by B. H. Brough); the 2nd Edition of Prof. E. Kayser's 'Allgemeine Geologie'; Dr. F. H. Hatch's & Dr. G. S. Corstorphine's 'Geology of South Africa'; Mr. A. W. Rogers's 'Geology of Cape Colony'; Mr. F. W. Rudler's 'Handbook to a Collection of Minerals of the British Islands'; Parts I & II of Dr. L. Carez's 'Géologie des Pyrénées françaises'; Prof. Lacroix's great monograph on 'La Montagne Pelée & ses Éruptions'; Mr. R. L. Galloway's 'Annals of Coal-Mining'; Dr. J. E. Marr's 'Introduction to Geology'; the first volume of the Monograph on the Rocks of Cape-Colville Peninsula (N.Z.) by Prof. W. J. Sollas & Dr. A. McKay; also 'The Age of the Earth & other Studies,' by Prof. W. J. Sollas; the Geological Survey-Memoirs on the North Staffordshire Coalfields, on the Country between Derby, Burton-on-Trent, & Ashby-de-la-Zouch (with a Chapter on Charnwood), on the Country south & east of Devizes, on the Geology of Bridgend, on the Water-Supply of Lincolnshire, on West-Central Skye and on Blair Atholl, and on the Country around Cork & Cork Harbour. Among the numerous publications received from the United States Geological Survey was Prof. C. R. Van Hise's 'Treatise on Metamorphism'; and special mention is due to Prof. A. Heim's great monograph on the Säntis Range, published by the Swiss Geological Commission. The German Colonial Office presented its official monograph on the Geology of the Cameroons; and publications, too numerous to particularize in

this place, were received from the Geological Surveys and other Government Departments of Egypt, India, the South African Colonies, Canada, the various States of the Australian Commonwealth, Alabama, Georgia, Iowa, Indiana, Missouri, Maryland, New Jersey, and Ohio; from those also of Japan, Russia, the Dutch East Indies, Portugal, and Prussia.

Dr. J. W. Evans presented twenty-five lantern-slides of the microscopic rock-sections exhibited in illustration of his paper on the Cataracts of the Rio Madeira, etc.; and the Society's collection of the portraits of eminent geologists was enriched by the following much appreciated gifts: framed photograph of the late Dr. W. T. Blanford, presented by Mrs. Blanford; framed photograph of Prof. J. W. Judd, presented by himself; portrait of Prof. T. McKenny Hughes, presented by Dr. Henry Woodward; and framed photograph of the late Prof. J. P. Lesley, For.Mem.G.S., presented by Sir Archibald Geikie.

The Books, Maps, etc. enumerated above were the gift of 175 Personal Donors; 123 Government Departments and other Public Bodies; and 164 Societies and Editors of Periodicals.

The Purchases, made on the recommendation of the standing Library Committee, included 58 Volumes and 10 Parts of separately-published Works; 38 Volumes and 12 Parts of Works published serially; and 13 Sheets of Maps.

Further progress has been made during the past year in overtaking the arrears of binding and map-mounting. No less than 120 Sheets of Maps have been mounted; and the Junior Assistant (Alec Field) has classified under their separate authors, and sent to the binders, about 360 Volumes of Tracts, representing the accumulations of some twenty years.

The Expenditure incurred in connexion with the Library during 1905 was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased..........	81	4	4
Binding of Books and Mounting of Maps....	163	6	1
	£244	10	5

being £44 10*s.* 5*d.* in excess of the amount provided for in the Estimates for that year.

With regard to the progress of the new Card-Catalogue of the Library, upon which he is engaged, Mr. C. Davies Sherborn supplies the following particulars:—

'The Card-Catalogue is now compiled up to the end of 1901. 1902 is almost ready, and 1903 and 1904 will be ready by June next. Revision and additions dealing with the contents of the periodical publications will shortly be commenced. The revision will permit of considerable reduction in the number of cards, thereby facilitating the use of the Catalogue; and it is hoped that Fellows will use the cards themselves, and thus relieve the pressure on those members of the staff who assist in the Library.'

Museum.

For the purpose of study and comparison, the Collections were visited on 18 occasions during the year, the contents of about 55 drawers being thus examined. Moreover, the permission of the Council having been duly obtained, about 90 specimens were lent during 1905 to various investigators.

No expenditure has been incurred in connexion with the Society's Museum during the past year.

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review:—

I. Government Departments and other Public Bodies.

Alabama.—Geological Survey, University (Ala.).
American Museum of Natural History. New York.
Australia (S.), etc. *See* South Australia, *etc.*
Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.
Bavaria.—Königliches Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique. Brussels.
——. Musée Royal d'Histoire Naturelle. Brussels.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
Birmingham, University of.
Bohemia.—Royal Museum of Natural History. Prague.
——. Naturwissenschaftliche Landesdurchforschung. Prague.
British Columbia.—Department of Mines, Victoria (B.C.).
British Guiana.—Department of Mines. Georgetown.
British South Africa Company. London.
Buenos Aires.—Museo Nacional de Buenos Aires.
California, University of. Berkeley (Cal.).
Cambridge (Mass.).—Museum of Comparative Zoology, Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
——, High Commissioner for. London.
Cape Colony.—Department of Agriculture: Geological Commission. Cape Town.
——. South African Museum. Cape Town.
Carolina (N.).—Geological Survey. Raleigh (N. Car.).
Chicago.—'Field' Columbian Museum.
Cordoba (Argentine Republic).—Academia Nacional de Ciencias.
Cracow.—Académie des Sciences. (Akademie Umiejetnosci.)
Denmark.—Commission for Ledelsen af de Geologiske og Geographiske Undersögelser i Grönland. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works: Geological Survey. Cairo.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Georgia.—Geological Survey. Atlanta (Ga.).
Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle an der Saale.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.

Great Britain.—Geological Survey. London.
——. Home Office. London.
——. India Office. London.
Holland.—Departement van Kolonien. The Hague.
Hull.—Municipal Museum.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
India.—Geological Survey. Calcutta.
——. Surveyor-General's Office. Calcutta.
Iowa Geological Survey. Des Moines (Iowa).
Ireland.—Department of Agriculture & Technical Instruction. Dublin.
Italy.—Reale Comitato Geologico. Rome.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Jassy, University of.
Kansas.—University Geological Survey. Lawrence (Kan.).
Kingston (Canada).—Queen's College.
London.—City of London College.
——. Imperial Institute.
——. Royal College of Surgeons.
——. University College.
Mexico.—Instituto Geológico. Mexico City.
Michigan College of Mines. Houghton (Mich.).
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Missouri.—Bureau of Geology & Mines. Jefferson City (Mo.).
Montana University. Missoula (Mont.).
Munich.—Königliche Bayerische Akademie der Wissenschaften.
Mysore Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
Naples.—Accademia delle Scienze.
Natal.—Department of Mines. Pietermaritzburg.
——. Geological Survey. Pietermaritzburg.
Newcastle-upon-Tyne. Armstrong College.
New Jersey.—Geological Survey. Trentham (N.J.).
New South Wales, Agent-General for. London.
——. Department of Mines & Agriculture. Sydney (N.S.W.).
——. Geological Survey. Sydney (N.S.W.).
New York State Museum. Albany (N.Y.).
New Zealand.—Department of Mines. Wellington (N.Z.).
Norway.—Geological Survey. Christiania.
Nova Scotia.—Department of Mines. Halifax (N.S.).
Ohio.—Co-operative Topographical Survey. Springfield (Ohio).
——. Geological Survey. Columbus (Ohio).
Padua.—Reale Accademia di Scienze, Lettere & Arti.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Peru.—Ministerio de Fomento. Lima.
Pisa, Royal University of.
Portugal.—Commissão dos Trabalhos geologicos. Lisbon.
Prussia.—Ministerium für Handel & Gewerbe. Berlin.
——. Königliche Preussische Geologische Landesanstalt. Berlin.
Queensland, Agent-General for. London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Redruth School of Mines.
Rhodesia.—Chamber of Mines. Bulawayo.
Rhodesian Museum. Bulawayo.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Russia.—Comité Géologique. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
South Australia, Agent-General for. London.
——. Geological Survey. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.

Tasmania.—Secretary for Mines. Hobart.
Tokio.—Imperial University.
——. College of Science.
Transvaal.—Geological Survey. Pretoria.
——. Mines Department. Pretoria.
Turin.—Reale Accademia delle Scienze.
United States.—Geological Survey. Washington (D.C.).
——. Department of Agriculture. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, University of.
Victoria (Austral.), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington (D.C.).—Smithsonian Institution.
—— (U.S.A.).—Geological Survey. Olympia (Wash.).
West Indies.—Imperial Agricultural Department. Bridgetown (Barbados).
Western Australia, Agent-General for. London.
——. Department of Mines. Perth (W.A.).
——. Geological Survey. Perth (W.A.).
Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).

II. Societies and Editors.

Acireale.—Accademia di Scienze, Lettere & Arti.
Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-Naturalis Croatica.
Alnwick.—Berwickshire Naturalists' Club.
Basel.—Naturforschende Gesellschaft.
Bath.—Natural History & Antiquarian Field-Club.
Belgrade.—Servian Geological Society.
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. 'Zeitschrift für Praktische Geologie.'
Berne.—Schweizerische Naturforschende Gesellschaft.
Bishop Auckland.—Wearside Naturalists' Field-Club.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.) Society of Natural History.
——. American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brooklyn (N.Y.) Institute of Arts & Sciences.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société belge de Géologie, de Paléontologie & d'Hydrologie.
Budapest.—Földtani Közlöny.
Buenos Aires.—Sociedad Científica Argentina.
Bulawayo.—Rhodesian Scientific Association.
Caen.—Société Linnéenne de Normandie.
Calcutta.—'Indian Engineering.'
——. Asiatic Society of Bengal.
Cambridge Philosophical Society.
Cape Town.—South African Association for the Advancement of Science.
——. South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chicago.—'Journal of Geology.'
Christiania.—Norsk Geologisk Forening.
——. 'Nyt Magazin for Naturvidenskaberne.'
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—'Colorado College Studies.'
Croydon Microscopical & Natural History Society.
Denver.—Colorado Scientific Society.
Dorpat (Jurjew).—Naturforschende Gesellschaft.
Dresden.—Naturwissenschaftliche Gesellschaft.
——. Verein für Erdkunde.
Edinburgh.—Royal Scottish Geographical Society.
——. Royal Society.

Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Falmouth.—Royal Cornwall Polytechnic Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Geneva.—Société de Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.
Halifax (N.S.).—Nova Scotian Institute of Science.
Hanau.—Wetterauische Gesellschaft für Gesammte Naturkunde.
Havre.—Société Géologique de Normandie.
Hertford.—Hertfordshire Natural History Society.
Hull Scientific & Naturalists' Field-Club.
Indianapolis.—Indiana Academy of Science.
Johannesburg.—Geological Society of South Africa.
Kiev.—Société des Naturalistes.
Lausanne.—Société Vaudoise des Sciences Naturelles.
Lawrence (Kan.).—'Kansas University Bulletin.'
Leeds Philosophical & Literary Society.
——. Yorkshire Geological & Polytechnic Society.
Leicester Literary & Philosophical Society.
Leipzig.—'Zeitschrift für Krystallographie & Mineralogie.'
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences.
Lille.—Société Géologique du Nord.
Lima.—'Revista de Ciencias.'
Lisbon.—Sociedade de Geographia.
Liverpool Geological Society.
——. Literary & Philosophical Society.
London.—'The Athenæum.'
——. British Association for the Advancement of Science.
——. British Association of Waterworks Engineers.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. East India Association.
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institute of Sanitary Engineers.
——. Institution of Civil Engineers.
——. Institution of Mining & Metallurgy.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Journal.'
——. 'Nature.'
——. Palæontographical Society.
——. 'The Quarry.'
——. Records of the London & West-Country Chamber of Mines.
——. Royal Agricultural Society.
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Society of Arts.
——. Society of Biblical Archæology.
——. 'The South-Eastern Naturalist' (S.E. Union of Scientific Societies).
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester Geological & Mining Society.
——. Literary & Philosophical Society.
Melbourne.—Australasian Institute of Mining Engineers.

Melbourne.—Royal Society of Victoria.
Mexico.—Sociedad Científica 'Antonio Alzate.'
Moscow.—Société Impériale des Naturalistes.
New Haven (Conn.).—'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'
Newcastle-upon-Tyne.—The Institution of Mining Engineers.
——. North-of-England Institute of Mining & Mechanical Engineers.
Northampton.—Northamptonshire Natural History Society.
Oporto.—Academia polytecnica. [Coimbra.]
Ottawa.—Royal Society of Canada.
Paris.—Commission Française des Glaciers.
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
——. Wagner Free Institute of Science.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Academy of Science.
——. Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
——. Société Scientifique du Chili.
São Paulo.—Sociedade Scientifica.
Scranton (Pa.).—'Mines & Minerals.'
St. John (N.B.).—Natural History Society of New Brunswick.
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—'Centralblatt für Mineralogie, Geologie & Paläontologie.'
——. 'Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.'
——. Oberrheinischer Geologischer Verein.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. 'Zeitschrift für Naturwissenschaften.'
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Vienna.—'Beiträge zur Paläontologie und Geologie Œsterreich-Ungarns & des Orients.'
——. 'Berg- & Hüttenmännisches Jahrbuch.'
——. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Biological Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
York.—Yorkshire Philosophical Society.

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Wardle, Sir Thomas.
Wetherell, E. W.
Whitaker, W.
Wilckens, O.
Wiman, C.
Woodward, Henry.
Woodward, Horace B.

Yeates, W. S.

Zeiller, R.

Comparative Statement of the Number of the Society at the Close of the Years 1904 and 1905.

	Dec. 31st, 1904.		Dec. 31st, 1905.
Compounders	281	......	280
Contributing Fellows......	934	......	926
Non-Contributing Fellows..	36	......	33
	1251		1239
Foreign Members	40	......	40
Foreign Correspondents....	40	......	38
	1331		1317

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1904 and 1905.

Number of Compounders, Contributing and Non-Contributing Fellows, December 31st, 1904 ..			1251
Add Fellows elected during the former year and paid in 1905			13
Add Fellows elected and paid in 1905			36
			1300
Deduct Compounders deceased................		5	
Contributing Fellows deceased		18	
Non-Contributing Fellows deceased		3	
Contributing Fellows resigned		19	
Contributing Fellows removed		16	
		—	61
			1239
Number of Foreign Members and Foreign Correspondents, December 31st, 1904		80	
Deduct Foreign Members deceased	2		
Foreign Correspondent deceased	1		
Foreign Correspondents elected Foreign Members	2		
	—	5	
		75	
Add Foreign Members elected	2		
Foreign Correspondent elected	1		
	—	3	
		—	78
			1317

Deceased Fellows.

Compounders (5).

Blanford, Dr. W. T.
Durham, J.
Hutton, Capt. F. W.
Kirkpatrick, J.
Slade, J.

Resident and other Contributing Fellows (18).

Anderson, J.
Bompas, G. C.
Booth, I.
Clague, D.
Forster, T. C.
Fotherby, Dr. H. I.
Gaskell, F.
Horsley, C.
Johnson, J. C. F.
Jones, D. W.
Knightley, T. E.
Mansergh, J.
Shore, T. W.
Sloper, E.
Streich, V.
Tonge, J.
Twite, C.
Woodall, J. W.

Non-contributing Fellows (3).

Farrar, Rev. A. S.
Medlicott, H. B.
Phear, Sir John B.

Deceased Foreign Members (2).

Dewalque, Prof. G.
Richthofen, Baron F. von.

Deceased Foreign Correspondent (1).

Raulin, Prof. V.

Fellows Resigned (19).

Cadell, H. M.
Charlton, G.
Crompton, A.
Gard, W. G. S.
Gibbes, Dr. C. C.
Hutchinson, W.
Hyslop, Rev. J.
Montefiore-Brice, A.
Murdoch, T.
Parsons, C. E.
Rutland, J.
Smith, J. T.
Stephens, F. B.
Sykes, B.
Taylor, J.
Viccars, T.
Warren, Sir Charles.
Williams, Rev. H. A.
Winstone, B.

Fellows Removed (16).

Aird, R.
Birks, L.
Brogden, J.
Cairnes, E. M.
Franchy, A.
George, T. J.
Hawkins, C.
Howarth, O. H.
Kendall, J. D.
Negus, J.
Nœtling, F.
Rickard, F.
Scott, J.
Sheppard, Rev. J. E.
Small, J. W.
Wilson, A. P.

The following Personages were elected Foreign Members during the year 1905:—

Prof. Louis Dollo, of Brussels.
Prof. August Rothpletz, of Munich.

The following Personage was elected a Foreign Correspondent during the year 1905:—

Prof. Bundjirô Kôtô, of Tokyo.

After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to Dr. J. E. Marr, retiring from the office of President.

That the thanks of the Society be given to Prof. T. G. Bonney, Prof. Charles Lapworth, and Mr. Horace B. Woodward, retiring from the office of Vice-President.

That the thanks of the Society be given to Dr. F. A. Bather, Prof. J. W. Judd, Prof. P. F. Kendall, Prof. C. Lapworth, and Prof. H. A. Miers, retiring from the Council.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

OFFICERS AND COUNCIL.—1906.

PRESIDENT.

Sir Archibald Geikie, Sc.D., D.C.L., LL.D., Sec.R.S.

VICE-PRESIDENTS.

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J. E. Marr, Sc.D., F.R.S.
Aubrey Strahan, M.A., F.R.S.
J. J. H. Teall, M.A., D.Sc., F.R.S.

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Prof. E. J. Garwood, M.A.

FOREIGN SECRETARY.

Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S., F.L.S.

TREASURER.

Horace W. Monckton, Treas. L.S.

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Prof. E. J. Garwood, M.A.
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F. L. Kitchin, M.A., Ph.D.
Philip Lake, M.A.
G. W. Lamplugh, F.R.S.
Richard Lydekker, B.A., F.R.S.
Bedford McNeill, Assoc. R.S.M.
J. E. Marr, Sc.D., F.R.S.
Horace W. Monckton, Treas. L.S.
Frederick W. Rudler, I.S.O.
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Aubrey Strahan, M.A., F.R.S.
Charles Fox Strangways.
J. J. H. Teall, M.A., D.Sc., F.R.S.
Richard H. Tiddeman, M.A.
Prof. W. W. Watts, M.A., M.Sc. F.R.S.
The Rev. H. H. Winwood, M.A.
A. Smith Woodward, LL.D., F.R.S.
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LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1905.

Date of Election.

1874. Prof. Albert Jean Gaudry, *Paris.*
1877. Prof. Eduard Suess, *Vienna.*
1880. Prof. Gustave Dewalque, *Liége.* (*Deceased.*)
1880. Geheimrath Prof. Ferdinand Zirkel, *Leipzig.*
1884. Commendatore Prof. Giovanni Capellini, *Bologna.*
1885. Prof. Jules Gosselet, *Lille.*
1886. Prof. Gustav Tschermak, *Vienna.*
1888. Prof. Eugène Renevier, *Lausanne.*
1888. Baron Ferdinand von Richthofen, *Berlin.* (*Deceased.*)
1890. Geheimrath Prof. Heinrich Rosenbusch, *Heidelberg.*
1891. Prof. Charles Barrois, *Lille.*
1893. Prof. Waldemar Christofer Brœgger, *Christiania.*
1893. M. Auguste Michel-Lévy, *Paris.*
1893. Dr. Edmund Mojsisovics von Mojsvár, *Vienna.*
1893. Prof. Alfred Gabriel Nathorst, *Stockholm.*
1894. Prof. George J. Brush, *New Haven, Conn.* (*U.S.A.*).
1894. Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1895. Prof. Grove Karl Gilbert, *Washington, D.C.* (*U.S.A.*).
1895. Dr. Friedrich Schmidt, *St. Petersburg.*
1896. Prof. Albert Heim, *Zürich.*
1897. M. Édouard Dupont, *Brussels.*
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1900. Prof. Paul Groth, *Munich.*
1900. Dr. Sven Leonhard Tœrnquist, *Lund.*
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1901. Prof. Alfred Lacroix, *Paris.*
1903. Prof. Albrecht Penck, *Berlin.*
1903. Prof. Anton Koch, *Budapest.*
1904. Prof. Joseph Paxson Iddings, *Chicago* (*U.S.A.*).
1904. Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905. Prof. Louis Dollo, *Brussels.*
1905. Prof. August Rothpletz, *Munich.*

LIST OF
THE FOREIGN CORRESPONDENTS
OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1905.

Date of Election.

1866. Prof. Victor Raulin, *Montfaucon d'Argonne.* (*Deceased.*)
1874. Prof. Igino Cocchi, *Florence.*
1879. Dr. Émile Sauvage, *Boulogne-sur-Mer.*
1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1890. Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Kiel.*
1893. Prof. Aléxis P. Pavlow, *Moscow.*
1893. M. Ed. Rigaux, *Boulogne-sur-Mer.*
1894. M. Perceval de Loriol-Lefort, *Campagne Frontenex, near Geneva.*
1894. Dr. Francisco P. Moreno, *La Plata.*
1894. Prof. August Rothpletz, *Munich.* (*Elected Foreign Member.*)
1894. Prof. J. H. L. Vogt, *Christiania.*
1895. Prof. Constantin de Kroustchoff, *St. Petersburg.*
1896. Prof. Samuel L. Penfield, *New Haven, Conn.* (*U.S.A.*).
1896. Prof. Johannes Walther, *Jena.*
1897. Dr. Louis Dollo, *Brussels.* (*Elected Foreign Member.*)
1897. M. Emmanuel de Margerie, *Paris.*
1897. Prof. Count H. zu Solms-Laubach, *Strasburg.*
1898. Dr. Marcellin Boule, *Paris.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Göttingen.*
1899. Prof. Franz Lœwinson-Lessing, *St. Petersburg.*
1899. M. Michel F. Mourlon, *Brussels.*
1899. Prof. Gregorio Stefanescu, *Bucharest.*
1899. Prof. René Zeiller, *Paris.*
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1900. Prof. Federico Sacco, *Turin.*
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1904. The Hon. Frank Springer, *Burlington, Iowa* (*U.S.A.*).
1904. Dr. Henry S. Washington, *Locust, N.J.* (*U.S.A.*).
1905. Prof. Bundjirô Kôtô, Tôkyo.

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UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1831. Mr. William Smith.
1835. Dr. G. A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. H. Falconer.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron Leopold von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy.
1844. The Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. The Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. The Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Prof. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. Henry C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. Thomas H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Studer.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. William Thomas Blanford.
1884. Prof. Albert Jean Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Des Cloizeaux.
1887. Mr. John Whitaker Hulke.
1888. Mr. Henry B. Medlicott.
1889. Prof. Thomas George Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John Wesley Judd.
1892. Baron Ferdinand von Richthofen.
1893. Prof. Nevil Story Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie.
1896. Prof. Eduard Suess.
1897. Mr. Wilfrid H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Prof. Grove Karl Gilbert.
1901. Prof. Charles Barrois.
1902. Dr. Friedrich Schmidt.
1903. Prof. Heinrich Rosenbusch.
1904. Prof. Albert Heim.
1905. Dr. J. J. Harris Teall.
1906. Dr. Henry Woodward.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION-FUND.'

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. G. A. Mantell.
1836. Prof. G. P. Deshayes.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Prof. Edward Forbes.
1842. Prof. John Morris.
1843. Prof. John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape-of-Good-Hope Fossils. M. Alcide d'Orbigny.
1849. Mr. William Lonsdale.
1850. Prof. John Morris.
1851. M. Joachim Barrande.
1852. Prof. John Morris.
1853. Prof. L. G. de Koninck.
1854. Dr. Samuel P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Prof. G. P. Deshayes.
1857. Dr. Samuel P. Woodward.
1858. Prof. James Hall.
1859. Mr. Charles Peach.
1860. { Prof. T. Rupert Jones. Mr. W. K. Parker.
1861. Prof. Auguste Daubrée.
1862. Prof. Oswald Heer.
1863. Prof. Ferdinand Senft.
1864. Prof. G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Mr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. John Wesley Judd.
1874. Dr. Henri Nyst.
1875. Prof. L. C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. Robert Etheridge, Jun.
1878. Prof. William Johnson Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay Heatley Traquair.
1882. Dr. George Jennings Hinde.
1883. Prof. John Milne.
1884. Mr. Edwin Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Dr. Benjamin Neeve Peach.
1888. Dr. John Horne.
1889. Dr. Arthur Smith Woodward.
1890. Mr. William A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville Adelbert Derby.
1893. Mr. John George Goodchild.
1894. Mr. Aubrey Strahan.
1895. Prof. William W. Watts.
1896. Mr. Alfred Harker.
1897. Dr. Francis Arthur Bather.
1898. Prof. Edmund J. Garwood.
1899. Prof. John B. Harrison.
1900. Dr. George Thurland Prior.
1901. Mr. Arthur Walton Rowe.
1902. Mr. Leonard James Spencer.
1903. Mr. L. L. Belinfante.
1904. Miss Ethel M. R. Wood.
1905. Mr. H. H. Arnold-Bemrose.
1906. Dr. F. L. Kitchin.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1873. Mr. William Davies.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. The Rev. W. B. Clarke.
1878. Prof. Hanns Bruno Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. The Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. Waldemar C. Brœgger.
1892. Prof. A. H. Green.
1893. The Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustaf Lindstrœm.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. { Dr. Benjamin N. Peach.
Dr. John Horne.
1900. Baron A. E. Nordenskiœld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.
1903. Dr. Charles Callaway.
1904. Prof. George A. Lebour.
1905. Mr. Edward John Dunn.
1906. Mr. Charles T. Clough.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. Mr. Alfred Bell.
1874. Prof. Ralph Tate.
1875. Prof. H. Govier Seeley.
1876. Dr. James Croll.
1877. The Rev. John F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James Walker Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. Thomas Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Mr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward B. Wethered.
1891. The Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. Griffith J. Williams.
1894. Mr. George Barrow.
1895. Mr. Albert Charles Seward.
1896. Mr. Philip Lake.
1897. Mr. Sydney S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Mr. Thomas H. Holland.
1903. Mrs. Elizabeth Gray.
1904. Dr. Arthur Hutchinson.
1905. Mr. Herbert Lister Bowman.
1906. Mr. Herbert Lapworth.

AWARDS OF THE PROCEEDS

OF THE

'DANIEL-PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1903. Prof. Ernest Willington Skeats.
1904. Mr. Linsdall Richardson.
1905. Mr. Thomas Vipond Barker.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. Govier Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. Henry A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. Thomas Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. Edwin Tulley Newton.
1894. Prof. John Milne.
1895. The Rev. John F. Blake.
1896. Dr. Arthur Smith Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Dr. John Edward Marr.
1901. Dr. Ramsay Heatley Traquair.
1902. { Prof. Anton Fritsch. / Mr. Richard Lydekker. }
1903. Mr. Frederick William Rudler.
1904. Prof. Alfred Gabriel Nathorst.
1905. Dr. Hans Reusch.
1906. Prof. Frank Dawson Adams.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. Henry A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. The Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. Alfred J. Jukes-Browne.
1886. Mr. David Mackintosh.
1887. The Rev. Osmond Fisher.
1888. Dr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. M. Louis Dollo.
1890. Mr. Charles Davies Sherborn.
1891. Dr. C. I. Forsyth Major.
1891. Mr. George W. Lamplugh.
1892. Prof. John Walter Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Prof. Percy Fry Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William F. Hume.
1896. Dr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.
1901. Dr. John William Evans.
1901. Mr. Alexander McHenry.
1902. Dr. Wheelton Hind.
1903. Mr. Sydney S. Buckman.
1903. Mr. George Edward Dibley.
1904. Dr. Charles Alfred Matley.
1904. Prof. Sidney Hugh Reynolds.
1905. Mr. E. A. Newell Arber.
1905. Mr. Walcot Gibson.
1906. Mr. William G. Fearnsides.
1906. Mr. Richard H. Solly.

AWARD OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1903. John Lubbock, Baron Avebury.
1906. Mr. William Whitaker.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Prof. Othniel Charles Marsh.
1879. Prof. Edward Drinker Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Dr. J. J. Harris Teall.
1891. Dr. George Mercer Dawson.
1893. Prof. William Johnson Sollas.
1895. Mr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. E. David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.
1905. Prof. John Walter Gregory.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of Microscope.
1881. Purchase of Microscope-Lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Prof. Theodore T. Groom.
1902. Mr. William M. Hutchings.
1904. Mr. Hugh J. Ll. Beadnell.
1906. Mr. Henry C. Beasley.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				210	0	0
Due for Arrears of Admission-Fees	88	4	0			
Admission-Fees, 1906	207	18	0			
				296	2	0
Arrears of Annual Contributions	148	0	0			
Annual Contributions, 1906, from Resident and Non-Resident Fellows	1790	0	0			
Annual Contributions in advance	50	0	0			
				1988	0	0
Sale of Quarterly Journal, including Longmans' Account	......			160	0	0
Sale of Transactions, General Index, Library-Catalogue, Museum-Catalogue, Hutton's 'Theory of the Earth' vol. iii, Hochstetter's 'New Zealand,' and List of Fellows	......			6	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference-Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference-Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference-Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference-Stock	51	16	0			
Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock	8	0	0			
				351	16	0
Prestwich Trust-Fund: Repayment of Balance of Advance for Die of Medal	......			14	10	0
				3026	8	0
Estimated excess of Expenditure over Income	......			148	10	0
				£3174	18	0

the Year 1906.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House-Expenditure:						
Taxes		15	0			
Fire-Insurance	15	0	0			
Electric Lighting and Maintenance	50	0	0			
Gas	12	0	0			
Fuel	30	0	0			
Furniture and Repairs	30	0	0			
House-Repairs and Maintenance	30	0	0			
Annual Cleaning	15	0	0			
Tea at Meetings	20	0	0			
Washing and Sundry Expenses	35	0	0			
* Ventilation	90	0	0			
				327	15	0
Salaries and Wages, etc.:						
Assistant-Secretary	350	0	0			
" half Premium Life-Insurance	10	15	0			
Assistant-Librarian	150	0	0			
Assistant-Clerk	150	0	0			
Junior Assistant	65	0	0			
House-Porter and Upper Housemaid	95	0	0			
Under Housemaid	48	18	0			
Charwoman and Occasional Assistance	10	0	0			
Accountants' Fee	10	10	0			
				890	3	0
Office-Expenditure:						
Stationery	35	0	0			
Miscellaneous Printing, etc.	50	0	0			
Postages and Sundry Expenses	80	0	0			
* Lyell and Murchison Medals	13	0	0			
				178	0	0
Library (Books and Binding)				200	0	0
Library-Catalogue:						
* Cabinets	64	0	0			
Cards	30	0	0			
Compilation	50	0	0			
				144	0	0
Publications:						
Quarterly Journal, including Commission on Sale	1000	0	0			
Record of Geological Literature	150	0	0			
List of Fellows	35	0	0			
Postage on Journal, Addressing, etc.	90	0	0			
Abstracts, including Postage	110	0	0			
History of the Geological Society	50	0	0			
				1435	0	0
				£3174	18	0

* These items are of the nature of capital expenditure, or are not likely to recur.

HORACE W. MONCKTON, *Treasurer.*

January 25th, 1906.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1905	395	9	11			
,, Balance in the hands of the Clerk at January 1st, 1905	13	17	8	409	7	7
,, Compositions				137	18	0
,, Admission-Fees:						
Arrears	81	18	0			
Current	226	16	0	308	14	0
,, Arrears of Annual Contributions	155	8	0			
,, Annual Contributions for 1905:—						
Resident Fellows	1781	17	0			
Non-Resident Fellows	6	6	0			
,, Annual Contributions in advance	50	8	0	1993	19	0
,, Publications:						
Sale of Quarterly Journal: *						
,, Vols. i to lx	111	6	5			
,, Vol. lxi	41	11	9	152	18	2
,, Abstracts		4	6			
,, Record of Geological Literature ...	2	2	6			
,, List of Fellows		5	0			
,, Transactions	3	10	0			
,, Museum-Catalogue		10	6			
,, Hutton's 'Theory of the Earth,' vol. iii		2	6			
,, Hochstetter's 'New Zealand'		7	5	7	2	5
,, Repayment of Income Tax (1 year)				17	5	11
,, Prestwich Trust-Fund, part repayment of advance for Die of Medal				10	0	0
,, Dividends (less Income-Tax):—						
£2500 India 3 per cent. Stock....	71	5	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference-Stock	14	5	0			
£2250 London & North-Western Railway 4 per cent. Preference-Stock	85	10	0			
£2800 London & South-Western Railway 4 per cent. Preference-Stock	106	8	0			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference-Stock	49	4	2			
£267 6*s*. 7*d*. Natal 3 per cent. Stock	7	12	4	334	4	6
				£3371	9	7

* A further sum of £83 0 6 is due from Longmans & Co. for Journal-Sales.

Year ended December 31st, 1905.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire-Insurance	15	0	0			
Electric Lighting and Maintenance	61	6	5			
Gas	13	7	4			
Fuel	30	18	0			
Furniture and Repairs	33	18	2			
House-Repairs and Maintenance	41	15	4			
Annual Cleaning	12	10	3			
Tea at Meetings	19	14	10			
Washing and Sundry Expenses	33	17	10			
				263	3	2
,, Salaries and Wages:						
Assistant-Secretary	350	0	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	150	0	0			
Assistant-Clerk	150	0	0			
Junior Assistant	65	0	0			
House-Porter and Upper Housemaid	98	15	0			
Under Housemaid	48	5	9			
Charwoman and Occasional Assistance	8	8	6			
Accountants' Fee	10	10	0			
				891	14	3
,, Office-Expenditure:						
Stationery	32	8	5			
Miscellaneous Printing, etc.	70	11	4			
Postages and Sundry Expenses	76	1	9			
				179	1	6
,, International Catalogue of Scientific Literature				60	0	0
,, Library (Books and Binding)				244	10	5
,, Library-Catalogue				110	17	4
,, Publications:						
Quarterly Journal, Vol. l–lx, Commission on Sale thereof	9	6	9			
Quarterly Journal, Vol. lxi, Commission on Sale thereof	3	1	10			
Paper, Printing, and Illustrations	931	10	4			
Postage on Journal, Addressing, etc.	106	10	1			
Record of Geological Literature	123	0	2			
List of Fellows	36	0	0			
Abstracts, including Postage	107	11	0			
				1317	0	2
,, Balance in the hands of the Bankers at December 31st, 1905	288	15	7			
,, Balance in the hands of the Clerk at December 31st, 1905	16	7	2			
				305	2	9
				£3371	9	7

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

BEDFORD McNEILL, } *Auditors.*
JOHN SMITH FLETT, }

HORACE W. MONCKTON, *Treasurer.*

January 25th, 1906.

Statement of Trust-Funds: December 31st, 1905.

'Wollaston Donation-Fund.' Trust-Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1905	32	2	6	By Cost of Medal	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	11	6	,, Award from the Balance of the Fund	21	12	6
,, Repayment of Income-Tax (1 year)	1	12	4	,, Balance at the Bankers' at December 31st, 1905	32	3	10
	£64	6	4		£64	6	4

'Murchison Geological Fund.' Trust-Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1905	21	1	0	By Cost of Medal		17	0
,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture-Stock	38	0	4	,, Award to the Medallist	10	10	0
,, Repayment of Income-Tax (1 year)	1	19	2	,, Award from the Balance of the Fund	28	14	2
				,, Balance at the Bankers' at December 31st, 1905	20	19	4
	£61	0	6		£61	0	6

'Lyell Geological Fund.' Trust-Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1905	53	8	4	By Cost of Medal	1	1	0
,, Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	66	16	8	,, Award to the Medallist	25	0	0
,, Repayment of Income-Tax (1 year)	3	10	4	,, First Award from the Balance of the Fund	22	0	9
				,, Second Award from do.	22	0	9
				,, Balance at the Bankers' at December 31st, 1905	53	12	10
	£123	15	4		£123	15	4

'Barlow-Jameson Fund.' Trust-Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1905	16	3	8	By Balance at the Bankers' at December 31st, 1905	30	4	3
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture-Stock	13	6	10				
,, Repayment of Income-Tax (1 year)		13	9				
	£30	4	3				

'BIGSBY FUND.' TRUST-ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1905	10	1	0	By Cost of Medal	13	0	10
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	5	19	8	,, Balance at the Bankers' at December 31st, 1905	3	6	2
,, Repayment of Income-Tax (1 year)		6	4				
	£16	7	0		£16	7	0

'GEOLOGICAL RELIEF-FUND.' TRUST-ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1905	18	7	5	By Balance at the Bankers' at December 31st, 1905	22	10	11
,, Dividends (less Income-Tax) on the Fund invested in £139 3*s*. 7*d*. India 3 per cent. Stock	3	19	4				
,, Repayment of Income-Tax (1 year)		4	2				
	£22	10	11		£22	10	11

'PRESTWICH TRUST-FUND.' TRUST-ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1905	13	13	1	By Part Cost of Die	10	0	0
,, Dividends (less Income-Tax) on the Fund invested in £687 8*s*. 7*d*. India 3 per cent. Stock	19	11	8	,, Balance at the Bankers' at December 31st, 1905	24	3	11
,, Repayment of Income-Tax (1 year)		19	2				
	£34	3	11		£34	3	11

'DANIEL-PIDGEON FUND.' TRUST-ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1905	15	18	5	By Award	30	8	10
,, Dividends (less Income-Tax) on the Fund invested in £1019 1*s*. 2*d*. Bristol Corporation 3 per cent. Stock	29	0	10	,, Balance at the Bankers' at December 31st, 1905	16	0	11
,, Repayment of Income-Tax (1 year)	1	10	6				
	£46	9	9		£46	9	9

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

HORACE W. MONCKTON, *Treasurer*.

January 25th, 1906.

BEDFORD McNEILL,
JOHN SMITH FLETT, } *Auditors*.

Statement relating to the Society's Property :

December 31st, 1905.

	£	s.	d.	£	s.	d.
Balance in the Bankers' hands, December 31st, 1905 :						
On Current Account	288	15	7			
Balance in the Clerk's hands, December 31st, 1905	16	7	2			
				305	2	9
Due from Messrs. Longmans & Co., on account of Quarterly Journal, Vol. LXI, etc.	......			83	0	6
Arrears of Admission-Fees	88	4	0			
Arrears of Annual Contributions	170	11	6			
				258	15	6
				£646	18	9
Funded Property, at cost price :—						
£2500 India 3 per cent. Stock	2623	6	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference-Stock	502	15	3			
£2250 London & North-Western Railway 4 per cent. Preference-Stock	2898	10	6			
£2800 London & South-Western Railway 4 per cent. Preference-Stock	3607	7	6			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference-Stock	1850	19	6			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250	0	0			
				11,732	18	9

[*N.B.—The above amount does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications.*]

HORACE W. MONCKTON, *Treasurer.*

January 25th, 1906.

Award of the Wollaston Medal.

In presenting the Wollaston Medal to Dr. Henry Woodward, F.R.S., the President addressed him as follows:—

Dr. Woodward,—

The Wollaston Medal, the highest honour which it is in the power of the Society to bestow, has been unanimously awarded to you by the Council, in recognition of your researches concerning the mineral structure of the Earth, and particularly of your valuable contributions to the science of Palæontology, and more especially to our knowledge of the fossil Arthropoda.

There are many reasons why your fellow-workers and friends should rejoice at this award.

As Director of the Geological Department of the British Museum, your duties must have been heavy; but you have found time for an extraordinary amount of work, in addition to that necessitated by your official position.

Many are the learned Societies which are indebted to you for counsel. Besides our own, I may mention the Zoological, Palæontographical, Microscopical, and Malacological Societies, the Geologists' Association, and the Museums Association. Your labours on behalf of these Societies have been recognized by your having been called upon to occupy the Presidential Chair of the greater number of them.

The debt which geologists owe to you as Editor of the 'Geological Magazine' was admitted by Dr. Bonney, when, twenty years ago, on behalf of numerous subscribers he presented a testimonial to you in these Apartments. That debt is now more than doubled, for you have been Editor of the Magazine for over forty years, and during the greater part of that period its chief Editor. In addition to this we are deeply grateful to you, and especially to her who has ever interested herself in your labours, for the 'Index to the Geological Magazine' which appeared last year. It is a happy circumstance that the bestowal of this Medal upon you occurs in a month which witnesses the publication of the 500th number of that magazine. Long may the Magazine continue to flourish in the hands of its present Editor.

Dr. Bonney, on the occasion to which I have alluded, paid a just tribute to your great kindness to other workers, and especially to the encouragement that you have ever given to the young.

I gratefully remember the time when I, as an undergraduate, entered with feelings of trepidation the rooms of the Geological Department of the British Museum, then at Bloomsbury; how I was at once put at ease by you; and the help which I received. My experience has been that of many, and all who have benefited by your kindness will feel pleasure in the award of this Medal to you.

But, although the services which I have mentioned are reasons for rejoicing at the award, they are merely subsidiary reasons for the bestowal of the Medal. The recipients of the Wollaston Medal have always qualified for it by increasing our knowledge of the mineral structure of the Earth by their own researches. It is unnecessary to say that you also have done this. Your contributions to the study of the palæontology of the Invertebrates, and especially of the fossil Arthropoda, are known to all workers, and need no further comment on my part.

I am glad that, during the years of my occupation of this Chair, the Wollaston Medal has been awarded to two British geologists, the one a distinguished petrologist, the other an eminent palæontologist.

Dr. Woodward, in reply, said:—

Mr. President,—

It is now forty years ago (on February 16th, 1866) that I received from the President, Mr. William John Hamilton (at Somerset House), the award of the Balance of the Wollaston Donation-Fund. I was then only a youth of 34 years of age, and little dreamed that I should be honoured by receiving at your hands to-day this Medal, the highest recognition that the Council can bestow.

I feel justified, however, in attributing this great honour quite as much to the personal friendship of the Council, as to any merit of my own; but I am happy to find that this friendly disposition is also shared by a large body of the Fellows of the Society outside the Council, who have by letter and word of mouth expressed their kindly approval of the Council's choice.

I was elected a Fellow of this Society in 1864, and, from 1867 until 1902, I have been (off and on) a Member of the Council (for a period of 35 years), and served also the office of President (1894–96), so that I naturally feel more deeply interested in the welfare of this Society than in any other, although I have been

for many years, and am still, intimately associated with several other scientific bodies of kindred pursuits to our own.

You have alluded, Sir, in very favourable terms to my work, and I specially desire to thank you for your most kind reference to Mrs. Woodward's assistance in it, during all the years which are past, when we have worked side by side; but it would be incredible if, having had the grand opportunities afforded to me during 43 years in the British Museum, I had not winnowed out some store of good grain as a contribution to the stock of palæontological knowledge in so long a life.

Whether as Editor of the 'Geological Magazine,' or in the Geological Department of the British Museum, my greatest aim and object in life has always been to be of assistance to others, and for this, I am glad to say, I have won the friendship and goodwill of a very large circle of my fellow-workers, who have by their kindness rewarded me a hundred-fold, as you, Sir, in the name of the Council have done to-day by the bestowal of this Medal, for which my grateful thanks are due.

Award of the Murchison Medal.

The President then presented the Murchison Medal to Mr. Charles Thomas Clough, M.A., of H.M. Geological Survey, addressing him in the following words:—

Mr. Clough,—

The Council have awarded the Murchison Medal to you, in recognition of your invaluable contributions to Geological Science, by means of the maps and memoirs executed by you for H.M. Geological Survey.

Your detailed observations on the igneous and metamorphic rocks of Northern Britain have furnished geologists with most important material for the elucidation of many intricate problems. Your work is largely recorded in the various Memoirs of the Geological Survey. I may especially refer to those Memoirs which treat of the geology of the Cheviot Hills and of the Cowal District of Argyllshire, although your contributions to our science are also included in several other volumes of which you are one of the Authors.

Your work is also recorded on the maps of those areas which you have surveyed. To produce those maps required, in addition to the ordinary accomplishments of a geological surveyor, petrographical and other knowledge of a very special kind, and they form a fitting monument to your skill. Their remarkable execution was recognized by the selection of certain of those of Ross-shire for exhibition at the St. Louis Exhibition, as examples of the maps on the 6-inch scale which are produced by the Geological Surveyors of this country.

Once again the Murchison Medal is awarded to a member of that Survey of which the Founder was for so long Chief. It is a source of gratification to me that, in the two years of my office as President, medals have been awarded to two old members of my own College, pupils of my College-tutor, Dr. Bonney.

Mr. Clough replied as follows :—

Mr. President,—

I thank the Council of the Geological Society very much for the honour that they have conferred upon me, and you, Sir, for the very kind words in which you have spoken of my work. I am conscious that this presentation is a matter not purely personal to myself—that it is another recognition by this Society of the value of the detailed co-operative work carried on by the Geological Survey—and it is to me a great additional pleasure to be thus tacitly associated in your minds with colleagues and friends with whom I have spent so many happy years. I have now been on the staff of the Geological Survey for more than 30 years, and I have seen that we sometimes get on the wrong track—that we have our 'downs' as well as our 'ups'—but we feel that, through all vicissitudes, a foundation of honest work is always appreciated by our brethren of the hammer.

It is a pleasure also to acknowledge, on this occasion, my personal indebtedness to my old friends and teachers of Cambridge days, and particularly to Prof. Bonney and Prof. Hughes. I feel indeed that I owe to others more than I can tell.

Award of the Lyell Medal.

In handing the Lyell Medal, awarded to Prof. Frank Dawson Adams, Ph.D., to Sir Archibald Geikie, Sc.D., Sec.R.S., for transmission to the recipient, the President addressed him as follows:—

Sir Archibald Geikie,—

The Lyell Medal is awarded to Prof. Frank D. Adams as a mark of honorary distinction, and as an expression on the part of the Council that he has deserved well of the science, particularly by his contributions to our knowledge of the geology of Canada.

Prof. Adams has been actively engaged in the study of the rocks of the great Dominion, and by work in the field and the laboratory has contributed largely to our knowledge of their petrography and their genesis. The study of those ancient rocks, the pre-Cambrian age of which was first demonstrated in Canada, has advanced far during recent years; but they are still to some degree enshrouded in mystery, and the labours of our Medallist are throwing light upon the obscurity.

He is also occupied with work among igneous rocks bearing upon problems connected with petrographical provinces and the differentiation of igneous magmas. I may more especially allude to his paper on 'The Monteregian Hills—a Canadian Petrographical Province,' published in 'The Journal of Geology' for April–May 1903.

Nor has he occupied himself with observation to the neglect of experiment, and one result of his laboratory-work is that most interesting and suggestive paper, 'An Experimental Investigation into the Flow of Marble,' written in conjunction with Dr. J. T. Nicolson, and published in the Philosophical Transactions of the Royal Society (ser. A, vol. cxcv, 1901, p. 363). The experiments described in this paper tend to prove that not only

> 'The solid earth on which we stand,
> In tracts of fluent heat began,
> And grew to seeming-random forms,
> The seeming prey of cyclic storms,'

but that, even now, internal tracts which are in the ordinary sense solid,

> . . . . 'flow
> From form to form' . . . .

with results which have a most important effect upon various rock-structures.

Prof. Adams is successful also as a teacher, and we rejoice to know that, under his care, a geological school flourishes in McGill University, a university endeared to us all by its association with the name of Sir William Dawson.

We regret Prof. Adams's absence to-day. Let us hope that we may welcome him and many other geologists who are advancing our science in various parts of the Empire, on that auspicious occasion in the coming year, when we shall celebrate the centenary of the foundation of our Society.

Sir ARCHIBALD GEIKIE, in reply, expressed the pleasure with which he received this medal on behalf of his friend, Prof. Adams, from whom the following letter had just been received in answer to the Secretary's announcement of the Award:—

'Petrographical Laboratory, McGill University, Montreal, February 2nd, 1906.

'Professor EDMUND J. GARWOOD, M.A., Secretary of the Geological Society.

'Dear Sir,—

'I have received your kind letter conveying the very welcome and most unexpected information that the Council of the Geological Society have this year awarded to me the Lyell Medal. I regret extremely that it is impossible for me to be in London at the time of the Annual Meeting, so that I might have the pleasure of receiving the Medal in person.

'It is impossible for me to express adequately my thanks to the Council of the Geological Society for the great and unexpected honour which they have done me. Sir Charles Lyell's name, known as it is wherever Geology is taught, is among us here associated with very kindly memories. For, during his second visit to America, Sir Charles met Dr. (afterwards Sir William) Dawson, then a young man commencing his geological work, and with him visited and studied the now renowned Joggins section of the Carboniferous of Nova Scotia. Lyell's help, council, and encouragement at that time, greatly stimulated Dawson to increased endeavour and further work. In 1881 Dawson became the recipient of the Lyell Medal, indicating that his endeavours had been crowned with some measure of success. As Sir William Dawson was my earliest teacher in Geology, as well as my predecessor in the Chair which I now hold, the award of the Lyell Medal a second time to the Logan Professor of Geology at McGill University will still further serve to perpetuate Lyell's memory here, and to strengthen the bond of union between the geologists of Canada and the great Geological Society which has its seat at the Capital of the Empire.

'Please convey to the Council of the Society my sincere appreciation of the honour which they have done me, and accept my best thanks for the very kind words of your letter, in which you conveyed the announcement of the gift.

'I remain, yours most sincerely,

'FRANK D. ADAMS.'

Prof. Adams was still in the full vigour of life, and there was every reason to hope that his distinguished career would be prolonged

for many years to come. That his geological activity shows no sign of slackening is proved by an intimation which the speaker had recently received from him, that he had completed the detailed investigation of a wide Archæan tract of Canada, and that the paper containing the account of this investigation might be expected in this country at an early date. His researches on the flow of rocks are also still in progress, and some further results on this interesting subject may be looked for before long. No more fitting recipient of this medal could have been selected, than the geologist who carries on so ably the traditions of Logan and Dawson in Canada.

Award of the Prestwich Medal.

The President then presented the Prestwich Medal to Mr. William Whitaker, F.R.S., addressing him as follows:—

Mr. Whitaker,—

The Prestwich Medal is awarded to you, as an acknowledgment of the work that you have done for the advancement of geology, particularly by your researches among the Tertiary strata of the London and Hampshire Basins. Twenty years ago the Council awarded to you the Murchison Medal as an acknowledgment of your contributions to our science, which were particularized by the President of that day. Since then you have not been idle, and your recent work has been conducted on lines similar to those along which your earlier labours were carried on.

The Prestwich Medal is, however, doubtless awarded to you, not so much on account of what you have done since receiving the Murchison Medal, as in recognition of the value of your researches in those parts of our science which were advanced in a high degree by the Founder of the medal which I am about to hand to you, namely, the study of the Tertiary and Quaternary deposits. The importance of your labours among the Tertiary deposits was aptly acknowledged by Dr. Bonney in 1886, in the following words:

> 'Your papers on the western end of the London Basin, and on the Lower London Tertiaries of Kent, deserve to be ranked with the classic memoirs of Prestwich, as elucidating the geology of what I may call the Home District.'

You have also followed in the footsteps of Prestwich in matters of economic geology. I may especially refer to the question of

water-supply and to the study of underground geology, for which you, the recipient of the Medal, like its Founder, have done so much.

In these circumstances, it must be a source of satisfaction to you as well as to your friends, to find that the Council have added a new link connecting your name with that of Sir Joseph Prestwich.

Six years ago the honour fell to me of receiving a medal from your hands. It now falls to my lot to convey one to you, and it gives me much pleasure to hand it to a geologist with whom I have been on terms of friendship for thirty years.

Mr. Whitaker, in reply, said :—

Mr. President,—

During the course of my official life on the Geological Survey it was my lot to work over ground that had been examined in detail by Prestwich, and the geology of which was described in the remarkable set of papers which he read to the Society.

In my work I was struck by the accuracy of observation and the judgment in inference shown by our past master in stratigraphy.

In another matter, too, I have had to follow along a line in which Prestwich was perhaps the pioneer, that is the application of geology to questions of water-supply and kindred practical subjects.

It has been to me a constant pleasure to follow in the footsteps of one from whom I have learnt so much ; and that, in the opinion of the Council, I have been a not unworthy follower, is evidenced by the award to me of the Medal that bears his honoured name.

I am proud, therefore, to-day in having my name again associated with that of one for whom I have always had a great regard, as a geologist and as a friend.

Award of the Wollaston Donation-Fund.

In presenting the Balance of the Proceeds of the Wollaston Donation-Fund to Dr. Finlay Lorimer Kitchin, M.A., the President addressed him in the following words :—

Dr. Kitchin,—

The Balance of the Proceeds of the Wollaston Donation-Fund is awarded to you, as an acknowledgment of the value of your investigations on the Fossil Brachiopoda and other Invertebrata.

You took exceptional pains to fit yourself for your future calling by a prolonged course of study. After a successful career at Cambridge you proceeded to Munich, to study palæontology under a great Master—the revered Zittel. The results of your training have been already shown by your various papers on Invertebrate Palæontology, among which I would specially allude to your work on the Jurassic Fauna of Cutch, published in the 'Palæontologia Indica.'

In your present position your time, like that of most professional geologists, is no doubt largely occupied by routine-work, but what you have already done encourages us to hope that your contributions to the science of Palæontology will rank with those of your distinguished predecessors in the post which you now occupy.

Award of the Murchison Geological Fund.

The President then presented the Balance of the Proceeds of the Murchison Geological Fund to Mr. Herbert Lapworth, B.Sc., addressing him as follows:—

Mr. Herbert Lapworth,—

The Balance of the Proceeds of the Murchison Geological Fund is awarded to you, in acknowledgment of your investigations among the Llandovery rocks of the Rhayader district.

During the intervals of a busy professional life you have devoted your attention to a line of research with which the name of Lapworth will ever be associated. The success of your investigations will be admitted by all who have read your admirable paper in the 56th volume of our Quarterly Journal. Of that paper I need merely say that it is worthy of the son of Charles Lapworth. We trust that our Journal will, in future years, contain many other equally-valuable contributions from your pen.

I have much pleasure in handing to you this Award, bestowed by the Council as an incentive to further work.

Awards from the Lyell Geological Fund.

In presenting a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. William George Fearnsides, M.A., the President addressed him as follows:—

Mr. Fearnsides,—

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to you by the Council, in recognition of your valuable contributions to our knowledge of the Lower Palæozoic and the Cretaceous rocks.

Your first contribution to the Quarterly Journal recorded an interesting discovery on the borders of our University town, where one might have expected that little remained to be done. But, like so many Cambridge men, you, dissatisfied with the simplicity of the Mesozoic rocks of East Anglia, turned your attention to the older rocks of the western tracts of Britain; and that you have there already obtained most valuable results is proved by your admirable paper on 'The Geology of Arenig Fawr & Moel Llyfnant,' published in last year's Quarterly Journal.

Your friends know that this is but a beginning, and that you have already done much work in Wales and elsewhere which is not yet published. We shall look forward with confidence to the results of your continued researches; and it gives me much pleasure to hand to you this proof of the Council's approbation of what you have already done, and of their interest in your future work.

The President then handed the other moiety of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Mr. Richard H. Solly, M.A., to Prof. W. W. Watts, F.R.S., Sec.G.S., for transmission to the recipient, addressing him in the following words:—

Prof. Watts,—

The other moiety of the Lyell Geological Fund has been awarded to Mr. Richard H. Solly, as an acknowledgment of the valuable work done by him on the minerals of the Binnenthal and elsewhere. Mr. Solly has carried out his labours under difficulties, and

in some degree with a lack of encouragement which would have disheartened many workers. Nevertheless, he has steadily proceeded with his self-appointed task, and made substantial additions to his science. He is still engaged in his work on the Binnenthal, where he has discovered seven new minerals which he has described.

Will you express a hope to Mr. Solly that this Award may act as an incentive to the prosecution of his researches, proving as it does that his work is appreciated by the Council of this Society?

Award from the Barlow-Jameson Fund.

In presenting a sum of Twenty-Five Pounds from the Barlow-Jameson Fund to Mr. Henry C. Beasley, the President addressed him as follows:—

Mr. Beasley,—

The sum of Twenty-Five Pounds from the Barlow-Jameson Fund is awarded to you by the Council, in recognition of your important work on the Triassic rocks. In connexion with that work I may refer to your valuable descriptions of footprints from the Trias, in which you have abstained from burdening our fossil-lists with new names. You have travelled much on either side of the Atlantic, obtaining thereby much information concerning geological matters, more especially with reference to the Triassic rocks.

I may also allude to your work on Glacial Geology, and to a suggestive paper on the water ejected from volcanoes.

I hope that this award of the Council will encourage you in the further prosecution of your fruitful researches.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT.

JOHN EDWARD MARR, Sc.D., F.R.S.

I now proceed to give short accounts of those whom the hand of death has removed from among us in the course of the year. I have again to offer thanks to those who have been good enough to assist me in this task. They are Dr. C. W. Andrews, Prof. J. W. Gregory, Mr. R. S. Herries, Mr. R. Lydekker, and Mr. H. B. Woodward.

No loss is so heavy to us as that of WILLIAM THOMAS BLANFORD. A notice of Dr. Blanford by one who knew him long and well appears below, but I feel that I should not be doing my duty as one who has served on the Council with him for many years if I did not myself refer to the good work which he has done for our Society. He acted as Secretary from 1884 to 1888, occupied the Presidential Chair during the years 1888–1890, and was Treasurer from 1895 up to the time of his death last year.

The amount of work which he did for us in connexion with the Council and Committees was very great, but it was done so quietly, and was so complete when submitted to the various bodies, that only the Officers were aware of its extent, and even they could but approximately gauge it. He knew the geology of the world, and when any doubt would otherwise have arisen as to who was to be asked to consider the publication of a paper, Dr. Blanford was sure to be requested to peruse it, and I remember no case where he declined to do so, however great might be his stress of work. The smoothness which characterised his doings for us was due, not only to the completeness and quietness of his work, but in a very high degree to his unfailing kindness and courtesy to all with whom he came into contact. He was indeed one of those of whom the poet sings that—

> 'Lives of great men all remind us
> We can make our lives sublime,
> And, departing, leave behind us
> Footprints on the sands of time.'

FERDINAND PAUL WILHELM, BARON VON RICHTHOFEN might in 1860 have been mourned as a deserter from geology; but now geologists rejoice in the path that he chose, and mourn him in gratitude for his deep and beneficial influence on the study of structural geography.

He was born, of a distinguished Silesian family, at Karlsruhe, on May 5th, 1833. He was educated at Breslau, and, from 1852 to 1856, at the University of Berlin. Here his main study was geology, under Beyrich. But of his Berlin teachers, Richthofen probably owed most to the inspiration of the geographical teaching of Karl Ritter, whose philosophic spirit lived on in the work of his greatest pupil. Richthofen began research in petrology, and his first paper 'Ueber den Melaphyr,' the thesis for his doctorate, was published in 1856. It shows, in its full account of the literature, his historic sympathies, and also the value which he already attached to tectonic problems. Till 1859 he was engaged in geological surveys in the Tyrol and in Hungary. Most of his writings at this period deal with the eruptive rocks of Central Europe and the dolomites of the Tyrol. His interest in economic problems is shown by his paper on the ores associated with the Hungarian trachytes. It was during this period that Richthofen developed the first of the three important geological hypotheses with which his name will always be associated—the origin of the dolomite-blocks of the Tyrol.

Richthofen's surveys were interrupted in 1859 by his appointment as geologist with Count von Eulenburg's mission to Eastern Asia. This expedition enabled him, between 1860 and 1862, to make contributions to the knowledge of the geology and geography of Ceylon, Formosa, Japan, Java, the Philippines. Siam, and Further India. He left the mission in China on its return to Europe in 1862, and travelled overland to Moulmein. After a short visit to India he crossed to California. Here he spent six years. The chief result of his work there were his memoirs on the Comstock Lode (1866) and his 'Natural System of Volcanic Rocks' (1868).

In 1868 he returned to China, which was now open to travellers. Here he was occupied, until 1872, in the extensive journeys during which he collected the material for his great work, 'China,' and discovered the vast coal-fields of Shantung, thus enabling the world to realize the economic importance of China. His work has had a marked influence on world-politics, for his appreciation of the value of Kiaochau led to its selection as the base of German operations in the Far East. He returned to Europe in 1872, and was appointed Professor of Geology at Bonn, in 1875; but he was allowed to defer beginning his duties there till he had published some of the results of his Chinese travels.

He taught at Bonn from 1879 to 1883, when he accepted the Chair of Geography at Leipzig. In 1886 he was appointed Professor

of Physical Geography at Berlin, in which position he has done so much to give German geography its scientific spirit, and helped to secure the establishment in Berlin, in 1903, of an institute for the study of Oceanology. His teaching and his insistence on scientific precision in the terminology of descriptive geography have influenced a wider circle than his immediate pupils, thanks to his excellent 'Führer für Forschungsreisende' (1886). He died on October 6th, 1905.

Richthofen's greatest work is his 'China,' which will long remain a standard work of reference, owing to its great addition to the knowledge of a country previously almost unknown geologically. The work, however, is still unfinished. The first volume, published in 1877, contains an elaborate history of China, and its chief geological interest is the statement of his evidence as to the origin of lœss. The second volume deals with the Northern Provinces, and the fourth describes his palæontological collections. One volume of the Atlas with part of his maps was issued in 1885. But the rest of his maps and the third volume describing Southern China have not yet been published.

This solid addition to the materials of geology is perhaps of less value than Richthofen's stimulating influence on contemporary geological thought. His fine imagination led him to brilliant and illuminating ideas in each of the three departments of geology in which he worked—petrology, tectonic geology, and physical geology.

Petrology was his first love, and that at a time when he described it as 'still considered a very incomplete and little satisfactory part of geology.' He started work eager to remove this reproach, by giving more precise definitions of rock-names and a more instructive basis of rock-classification. So he compiled a synonymy and diagnosis of melaphyre as a rock-species, on lines similar to those adopted in systematic zoology. The methods by which he hoped to wrest from petrography the whole history of vulcanicity are best stated in his 'Natural System of Volcanic Rocks.' He had shown in 1859 a tendency to the main theory of that paper, in his discussion of the separation of melaphyre and augite-porphyry; for he then classified the Triassic eruptive rocks of the Tyrol into ten successive eruption-periods. Unfortunately, Richthofen's reasoning was based on the principles of petrology then dominant in Germany. Thus he resolutely separated the Scottish 'anamesites' by their younger age from the melaphyre, which he confined to eruptions

during the middle of his ten eruption-periods. It was the foundations that Richthofen accepted from his teachers, and not his methods that were at fault. But his speculations will always be of interest, from his early appreciation of the facts subsequently explained by magmatic differentiation; and from his attractive suggestion of fissure-eruptions, by which he sought to account for the occurrence of lavas on a scale transcending all European experience.

His most famous contribution to tectonic geology, though not confirmed by more detailed later surveys, was his explanation that the dolomite 'Colossi,' as he called them, of the Tyrol, were coral-atolls built in a Triassic sea; that the associated St. Cassian Beds were the contemporary deep-sea deposits, on the ocean-floor between the atolls; and that the Raibl Beds were mainly coral-sands on the shores of the atolls, or fragmental limestones formed between the reefs in the last stage of coral-formation. This hypothesis was announced in 1860 in his 'Geognostische Beschreibung von Predazzo,' and reasserted in 1874, in his paper on the Mendola Dolomite, and then supported by arguments derived from his study of living reefs in Malaysia.

Richthofen's most successful addition to geology was his solution of the vexed question of the origin of lœss, in a series of papers between 1872 and 1882, and mainly in the first volume of his 'China' in 1877. From the study of the lœss in Eastern China, he concluded that it must have been a subaërial steppe-formation. This inference from the lithological characters of the deposit he supported by study of its actual formation in progress in the steppes of Mongolia. The occurrence of lœss of identical composition, in Germany and Central Europe, led him to the opinion that steppe-conditions must once have prevailed there; and this conclusion, based on the evidence of physical geology, was fully confirmed when the palæontological work of Nehring showed that the bones in the German lœss belonged to a steppe-fauna. [J. W. G.]

Gilles Joseph Gustave Dewalque, who was elected a Foreign Correspondent in 1871 and a Foreign Member in 1880, was born at Stavelot in Belgium on the 2nd of December, 1826. He graduated as Doctor of Medicine and of Sciences in the University of Liége, and in 1857 succeeded Dumont in the Chair of Geology. In 1865 he was appointed Ordinary Professor of Mineralogy, Geology, and Palæontology, and only retired a few

years ago. He was one of the founders of the Société Géologique de Belgique.

His earlier researches were on the Lias of Luxemburg, and he published with F. Chapuis, in 1853, an important monograph, 'Description des Fossiles des Terrains Secondaires de la Province de Luxembourg'; but in the course of time he dealt with the stratified rocks and fossils of all ages in Belgium, from the Cambrian to the Scaldisian, and other subdivisions of the Tertiary system. Especially noteworthy are his contributions to our knowledge of the Devonian rocks and fossils.

He issued in 1868 'Prodrome d'une Description Géologique de la Belgique,' of which a second edition was published in 1880; and in 1879 he issued his 'Carte géologique de la Belgique et des Provinces voisines.'

He died at Liége on the 3rd of November, 1905.

[H. B. W.]

Félix Victor Raulin, who was elected a Foreign Correspondent in 1866, was born in Paris on the 8th of August, 1815. His attention was in early years directed to natural science, and more especially to geology; he joined the Geological Society of France in 1837, and became in 1838 Préparateur de Géologie at the Museum of Natural History at Paris. In 1846 he was appointed Professor of Mineralogy, Geology, and Botany at the Faculty of Sciences at Bordeaux, and this post he actively held until 1885, when he was made Emeritus Professor. He was distinguished for his researches on the geology of Aquitaine, on the Tertiary strata of the Paris Basin, of the Allier, and other parts of France. Among his separate works were 'Géologie de la France' 1844; 'Eléments de Géologie' 1868, 2nd ed. 1874 (written with special reference to the geology of France); and 'Description physique de l'Île de Crète' 2 vols. and atlas, 1869.

Regarded for some time as the Nestor of French geologists, he died on the 10th of February, 1905, at Montfaucon d'Argonne, in his 90th year. [H. B. W.]

By the death of William Thomas Blanford, C.I.E., LL.D., F.R.S., which took place at his residence, 72 Bedford Gardens, Campden Hill, London, on June 23rd, 1905, not only have our Society and geological science generally sustained a heavy loss, but an equally-wide gap has been made in the ranks of zoologists,

more especially in regard to the study of the geographical distribution of animals, in which our late colleague and Treasurer was one of the most distinguished writers. The eldest son of William Blanford, he was born at 27 Bouverie Street, Whitefriars, London, on October 7th, 1832, and was educated at first with a view to succeeding his father in business. Brighton first and Paris afterwards were the places where young Blanford received his early education; and on his return from the latter city in 1851, he appears for a short time to have actually begun work in business. Fortunately plans were changed, and in October of the following year he matriculated for a two years' course at the Royal School of Mines, where he passed out with high distinction, having gained two scholarships. On leaving the School of Mines, in 1854, the successful scholar was sent to pursue a course of study in mining and mineralogy at Freiberg; but, while thus engaged, he was offered and accepted a post on the Geological Survey of India, which was then being fully organized and equipped under the superintendentship of Dr. T. Oldham. Reaching India in September 1855, Blanford was despatched on his first field-work in the following January, the Talchir Coalfield of Orissa being the scene of his initial labours, and it was here that he made his mark by urging the glacial origin of the now well-known Talchir boulders.

To follow Blanford's earlier career on the Indian Survey would manifestly be out of place on this occasion, and it must suffice to state that, after doing much good work in surveying the Raniganj Coalfield and the rocks of Burma, he was appointed Deputy Superintendent in 1862, with special charge of the Bombay Presidency. The geology of the Narbada and Tapti Valleys, together with flying visits to Sind and Cutch, occupied much of his attention till 1866, in September of which year he was deputed to join the Abyssinian Expedition under Lord Napier, as geologist and naturalist. This expedition may be said to have formed a turning-point in his career, for there can be little doubt that it was while he was engaged on his Geology & Zoology of Abyssinia that his attention was first seriously directed to the problems of zoological geography. On his return to India in October 1868, with the Abyssinian war-medal as a recognition of his services, Blanford was engaged in working out his collections, a task which he was enabled to complete by being granted six months' leave on duty to England in the following spring. The results of his work were published in

1870, under the title of 'Observations on the Geology & Zoology of Abyssinia,' in a handsome and well-illustrated volume.

Back in India by November 1869, the following working seasons were spent in the Nagpur, Hazaribagh, Godaveri, and Ellori districts, while a vacation-trip was taken up the Sikhim Valley to the Tibetan frontier. In the winter of 1871–72, a plan for the detailed survey of Sind was interrupted by Blanford being ordered to join the Persian Boundary-Commission, under Major (afterwards Sir Oliver) St. John, in the same capacity as that in which he had served in Abyssinia. This gave another opportunity for the study of geographical distribution; and, at the conclusion of the expedition in 1872, Blanford enjoyed two years' home-furlough, during which he worked at his collections: the results of his labours being published in 1872 in the second volume of 'Eastern Persia.'

Returning to India in 1874, Blanford set to work on the postponed survey of Sind, where results of great interest, including a remarkably-large collection of echinoderms, were obtained. On the completion of the Sind work in 1877, Blanford, after writing a report on the same for the Survey Memoirs, joined Medlicott (who by this time had become chief of the Survey) in writing the 'Manual of the Geology of India,' an undertaking which will long keep alive the memory of the two authors. Two years (1879–1881) were again passed on furlough in England, at the close of which Blanford was deputed to visit the Geological Congress at Bologna, where he received the Order of St. Maurice & St. Lazarus from H.M. the King of Italy; and after returning for a short time to Sind, and thus completing 27 years' service on the Indian Survey, he finally retired on a pension in the spring of 1882. Had it not been for a slight seniority on Mr. Medlicott's part, Mr. Blanford would undoubtedly have been appointed Superintendent of the Indian Survey; and, to recompense him in some degree for this deprivation, the Government granted him a special allowance above the salary of his grade as Deputy-Superintendent. During his later Indian service he was President of the Asiatic Society of Bengal.

So early as 1874 Blanford was elected a Fellow of the Royal Society, and in 1883 he received from the Council of our own Society the award of the Wollaston Medal. In the same year he married Ida Gertrude, daughter of Mr. R. T. Bellhouse, and took up his residence at Campden Hill. Elected on our Council in 1883, Dr. Blanford served as Secretary from 1884 till 1888, when he was elected President; in the latter office his two addresses dealing

with the question of the permanency of ocean-barriers and continents, and the bearing of this on the past and present distribution of animal life, can be described in no other terms than as 'epoch-making.' Indian zoological provinces subsequently occupied much of his attention, and in acknowledgment of the importance of his work on this subject Blanford in 1901 received from the Royal Society the award of a Royal Medal. For ten years previous to his death, Dr. Blanford filled the office of Treasurer to our Society. He served twice for a period of two years on the Council of the Royal Society (in 1891–93 and 1901–1903), and was a Vice-President of the same body in 1892, 1901, and 1902. He also served on the Councils of the Royal Geographical and Zoological Societies, of both of which bodies he was a Vice-President. On four occasions he has been a Vice-President of Geological Congresses; and in 1884 he was President of the Zoological Section of the British Association at Montreal, on which occasion he received the degree of LL.D. from McGill University. In the year previous to his death the distinction of the Companionship of the Order of the Indian Empire was bestowed upon him. It should be added that Blanford was an honorary member of many foreign scientific societies; and also that during the Sepoy Mutiny he served with what is now the Calcutta Light Horse.

In addition to his work on the distribution of Indian animals, Blanford's time during his residence in England was largely occupied with the 'Fauna of British India,' a work which owed its inception entirely to his energy. Besides being editor of the series, he wrote the volume on mammals and two of those on birds, while at the time immediately preceding his death he was engaged on the land-shells. Thoroughness and breadth of view are distinctive of this and all his works, and his zoological writings are specially characterized by the manner in which he endeavoured to check the unnecessary multiplication of genera and species so much favoured by modern specialists. Indeed, it was a favourite saying of his that, in order to check such undue specialization, every scientific man ought to be a master of at least two branches of science. In connexion with his Indian Survey-work, special stress must be laid on Blanford's correction of the age of the Gondwana Series as deduced from the study of the land-flora.

As a man, Blanford was a true friend and trustworthy counsellor to all who enjoyed his full acquaintance. An innate shyness of manner gave the impression to younger men that he was haughty

and distant; but those who really knew him were aware that this was not the case, and there are many who, like the present writer, have lost by his death one of their best friends. Above all, Blanford was, in word and deed, a true gentleman. [R. L.]

By a remarkable coincidence HENRY BENEDICT MEDLICOTT, M.A., F.R.S., who joined the Geological Survey fifteen months earlier than Blanford, passed away two months earlier than his colleague, with whom he was so long and so intimately associated in official work. Born at Loughrea, County Galway (Ireland), on August 3rd, 1829, he was the second son of the Rev. Samuel Medlicott and Charlotte Medlicott, the former of whom was Rector of Loughrea. He was educated at first in France and Guernsey, and finally at Trinity College, Dublin, where he obtained his B.A. degree in 1850, with honours, in the School of Civil Engineering, although he did not take his M.A. till 1870.

In 1851 Medlicott was appointed to the Geological Survey of Ireland, but two years later he was transferred to the English Survey, and in March 1854 was engaged by Dr. T. Oldham as a member of the staff of the Indian Geological Survey. Before, however, he entered on the field-work of the Survey he was gazetted Professor of Geology in the Indian Engineering College at Rurki; but he was still allowed, by special arrangement, to do field-work for the Survey during the cold weather. Accordingly he acted as an extra member of the Survey staff during part of each year from 1854 to 1862, in which latter year he was definitely reinstated in his old appointment, with the rank of Deputy-Superintendent for the Bengal Presidency. During his temporary attachments to the Survey, Medlicott examined and classified the rocks of part of the Narbada Valley and Bundelkund, and subsequently those of the Outer Himalaya, where he established the distinction between the typical Siwaliks and the Manchars. In 1857 he served as a volunteer with the Rurki garrison against the Sepoy mutineers, when he gained the Mutiny Medal, after performing an act of gallantry almost unequalled and never surpassed.

After much excellent field-work in various parts of the vast Province under his geological charge, and having twice acted as Superintendent during Dr. Oldham's absence on furlough, Medlicott was appointed to the Superintendentship of the Survey, as being the senior officer, on the retirement of Dr. Oldham on April 1st, 1876; the title of the post being changed to Director in 1885.

Almost immediately he set to work, in association with Dr. Blanford, on the 'Manual of the Geology of India,' the first two volumes of which form a permanent memorial to the two authors and colleagues. Having reached the age-limit of service in 1884, Medlicott was accorded by Government an extension till 1887, in April of which year he surrendered the reins of office to Dr. King, after completing 33 years' service, most of which was spent in India.

During his Indian service Mr. Medlicott married Louisa, second daughter of the Rev. D. H. Maunsell, who survives him. While Superintendent (or Director) of the Survey, Medlicott, during his wife's absence in England, lived almost the life of a hermit when on office-duty in Calcutta—a course which did not perhaps tend to promote the welfare of his department. In addition to writing his share of the 'Manual,' Medlicott edited some ten volumes of the Survey-Memoirs, as well as other official publications. His policy of allowing his subordinates to express their views in print without censorship, even if he believed them to be wrong, gave rise to some amount of friction; but otherwise his rule—mild but firm—was beneficial to the general interests of the Survey. While Blanford's work inclined strongly to the palæontological side, that of Medlicott was strictly confined to the stratigraphical aspect. How much he accomplished in unravelling the tangled skein of Indian Geology may be learnt by reference to the Survey-publications and, more concisely, by the memoir of Medlicott written by his colleague Blanford only a few weeks before his own death, and published in the 'Records' of the Survey for 1905. It may be said, however, that during his Directorship he absolutely devoted himself, body and soul, to the duties of his office.

After his retirement Medlicott lived very quietly at Clifton, Bristol, where he passed away on April 6th, 1905, while seated in his study. In 1856 Medlicott became a Fellow of our Society, from which he received the Wollaston Medal, on his retirement from the Indian Geological Survey, in 1888. He was elected a Fellow of the Royal Society in 1877, and was also honorary Fellow of several foreign scientific societies; but he never used any distinctive letters after his name. In disposition he was retiring and shy to a degree, although affectionate to, and beloved by, the few with whom he was intimate. The present writer is indebted to him for many a kindness and much consideration. [R. L.]

In Frederick Wollaston Hutton, who died on October 27th, the Society has lost a Fellow of long standing, with whom few of us were, till a few months ago, personally acquainted, but who was widely known for the excellent geological and other scientific work which he had done in the country of his adoption. He was one of a pioneer-band of geologists, of whom Sir James Hector is perhaps the only survivor, who settled in New Zealand many years ago, and devoted themselves to working out the many complicated problems that the islands forming that colony present. He emigrated in 1866, and never returned to this country till last year, a period of 39 years. He attended the meeting of the Society on May 10th, and gave an admirable summary of a long and intricate paper by his old pupil, Dr. Patrick Marshall, on 'The Geology of Dunedin,' a model of condensation which might be copied with advantage by many readers of papers at our evening-meetings. On that occasion he remarked that the last meeting at which he was present had been in Somerset House, when the assemblage included such celebrities as Murchison and Lyell. Unfortunately, ill-health prevented him from being present at any more meetings, and from enjoying his visit home as he had hoped; and he was not destined again to see New Zealand, as he died on board ship during the return-voyage, before reaching Cape Town.

Capt. Hutton was born in 1836, the son of a Lincolnshire clergyman. He began life in the Mercantile Marine, but afterwards, in 1855, entered the Army as an Ensign in the 23rd Welsh Fusiliers, in which regiment he served till 1865, attaining the rank of Captain in that year. He saw service in the Crimea and in the Indian Mutiny, and (1860–61) passed through the Staff College at Sandhurst, where geology was already being taught by Prof. T. Rupert Jones. From that period, his love for geology and subsequent devotion to science seem to date. He became a Fellow of this Society in 1860, and in the following year contributed to the 'Geologist' an article entitled 'Some Remarks on Mr. Darwin's Theory,' a subject in which he always took a great interest, and to which he returned many years later in 'Darwinism & Lamarckism, Old & New,' and 'The Lesson of Evolution,' published in 1899 and 1902 respectively. This was followed by a paper in the 'Geological Magazine' for 1866, on the Geology of Malta, and from that time his contributions to science deal almost exclusively with New Zealand, to which colony, as already stated, he went out in the last-named year. After farming for a few years in the Waikato (Auckland Province), he joined the Geological Survey at Wellington,

being transferred in 1873 to Dunedin, as Provincial Geologist of Otago, and Curator of the Museum there. Subsequently he became Professor of Natural Science in the Otago University; and in 1890 he moved to Christchurch, on being appointed Professor of Biology and Geology in the Canterbury College of the University of New Zealand. He relinquished that post in 1893, to take up the position of Curator of the Christchurch Museum, which he held until his death. His knowledge of the country, it will be seen, was very wide, and not less so was the range of his numerous scientific writings. Besides geology, these deal with zoological, botanical, and ethnological subjects; and it is surprising to note in how many branches of science he was interested, on most of which he wrote with acknowledged authority. The great majority of his papers appeared in the Transactions of the New Zealand Institute, of which body he was elected President in 1904, but he also contributed to other periodicals, both in the colonies and in this country, particularly to the 'Geological Magazine' and the 'Ibis,' the study of birds having been the subject which interested him most next to geology. Many of his geological writings were on questions of local stratigraphy, but he also dealt with subjects of more general interest, such as mountain-formation and glaciation. To our own Quarterly Journal he contributed no less than eight papers: the first on 'Nga Tutura, an Extinct Volcano,' appearing in the volume for 1869, followed by others in 1873, 1885, 1887, 1888, and 1893. Of these it will be sufficient to specify the 'Synopsis of the Younger Formations of New Zealand' in vol. xxix, the very useful 'Sketch of the Geology of New Zealand' in vol. xli, and his account of 'The Eruption of Mount Tarawera' in vol. xliii. The latter was the result of a survey of the district affected by the great eruption which destroyed the celebrated terraces of Rotomahana, undertaken within a few weeks of the outbreak, no doubt at some personal risk. In his geological writings Hutton was somewhat of a controversialist, and his interpretations were not always accepted by his brother-geologists in New Zealand; but he was always regarded as an authority on the questions that he discussed, and, where he differed from others, he was invariably ready to acknowledge that they might after all be right.

He was elected a Corresponding Member of the Zoological Society in 1872, and a Fellow of the Royal Society in 1892, and in 1901 he was President of the Australasian Association for the Advancement of Science. [R. S. H.]

James Mansergh, the eminent engineer, was born at Lancaster in 1834. His native town, small when compared with most of the manufacturing towns of the county, may well be proud that in the course of a single century it produced four men like Dr. Whewell, Sir Richard Owen, Sir William Turner, and Mr. Mansergh.

Though his early work was largely connected with railways, Mr. Mansergh subsequently devoted his attention chiefly to water-supply and the disposal of sewage, and was a leading authority upon both. He communicated no paper to our Society, but was one of the many eminent engineers whose work proves the practical value of geological knowledge. This was especially shown by his Elan Valley Water-Scheme for the supply of Birmingham, the idea for which occurred to him many years before it was carried to its successful issue, he having studied while still a young man the natural conditions of the district in which the reservoir was constructed.

Mr. Mansergh's services to his profession are recorded elsewhere. He was elected a Fellow of our Society in 1876, and of the Royal Society in 1901. In 1900 he became President of the Institution of Civil Engineers, and three years later received the honorary freedom of his native town. It is written of him that his 'unfailing courtesy and kindness of heart and his devotion to duty endeared him to all who knew him, and won for him the respect and admiration of all who came even into brief contact with him.' He died at his residence in Fitzjohn's Avenue on June 6th of last year.

Sir John Phear, late Chief Justice of Ceylon, was sixth wrangler at Cambridge in 1847, and was afterwards called to the Bar. While at Cambridge he wrote two elementary mathematical text-books, and in later life wrote a work on 'The Aryan Village in India & Ceylon,' and subsequently published works on economics. He died on the 8th of April, 1905, in his eighty-first year; he had been elected a Fellow of this Society as long ago as 1852. His brother, the late Master of Emmanuel College, is yet on our list of Fellows.

J. Woodall Woodall was for many years resident in Scarborough, of which town he was at one time mayor. He took great interest in geology and zoology, and was always ready to give help to others. His was a familiar figure at meetings of the British Association, and other scientific gatherings. He had been a Fellow of this Society since 1857.

On the 4th of last month occurred the death of WILLIAM HENRY GOSS, of Stoke-upon-Trent. Mr. Goss, who was born in London in 1833, spent his early days in study. Through the influence of a former Lord Mayor of London, Mr. Alderman Copeland, he became interested in the potter's art, and began the manufacture of pottery in 1858. His success was due to his high scientific attainments, in addition to his artistic faculty and his business-capacity. He is best known for his heraldic pottery, which has so extensive a sale. He not only originated this ware but invented the body, and also the variously-coloured enamels used in its manufacture. Mr. Goss was a man of wide learning, who wrote on many topics, including various antiquarian subjects. He was elected a Fellow of this Society in 1881.

THOMAS BARRON died of enteric fever at Port Sudan on the Red Sea coast on January 30th last, after a few days' illness, and was interred in that locality. He was born on July 13th, 1865, near Greenlaw (Berwickshire), his family having been long established on the Border. In 1887 he entered the Royal College of Science, and remained there first as student, afterwards as Demonstrator in Geology, for about eight years. He took the Associateship both in Zoology and Geology, gaining first-class honours in the latter subject. About the end of 1895 he was appointed to the newly-established Geological Survey of Egypt, and remained in that service until about two years ago, when he took the position of Government Geologist in the Sudan, a post which he occupied at the time of his death. Some of his most important contributions to geological science are 'The Topography & Geology of the Eastern Desert of Egypt' (written in conjunction with Dr. W. F. Hume) 1903; 'The Phosphatic Beds of Qift in Qena Mudiria' 1900; and a 'Note on the Occurrence of Lower Miocene Beds between Cairo & Suez' 1904. He accompanied an expedition to Abyssinia about three years ago, but the results do not seem to have been yet published.

Mr. Barron was a man of sound common-sense and cool judgment. The writer of this note had the privilege of accompanying him on the long and harassing desert-march from the Fayûm to Moghara, and, even under the most trying circumstances, always found him even-tempered and resourceful. His death leaves a serious gap in the little band of workers who are gradually clearing up the geology of Egypt and the Sudan. [C. W. A.]

The Influence of the Geological Structure of English Lakeland upon its present Features.—A Study in Physiography.[1]

Seated on the summit of Orrest Head one sunny day last summer, gazing at the length of Windermere stretched beneath, with its wooded islands and promontories; with, on the north, the fine screen of fells dominated by Scawfell; on the east, the hills near Sedbergh and Kirkby Lonsdale, with the flat top of Ingleborough rising behind; on the south, Morecambe Bay with its estuaries:—I felt that an endeavour to reconstruct the history of the features of that physiographical unit—the English Lakeland—as an illustration of the importance of the study of geological detail in its bearing upon the present physical aspect of the country would be useful. For, although Lakeland is physiographically a unit, I was reminded that its history is closely connected with that of the distant Ingleborough on the one hand, and with that of Morecambe Bay on the other; and this connexion has never been fully described.

That much has already been done is generally known; but, as the result of over thirty years' work in the district, I have been gradually led to recognize the importance of minor details, in addition to the main geological structure, as controlling factors in the physical configuration, and some of the conclusions which I have reached seem to me to be of more than local importance.

But, apart from any new light which I may be able to throw upon the surface-forms of the district, it is my object to prove, by a critical examination of this limited tract, that close application to geological matters is necessary, in order to illustrate the present physical conditions: in other words, that the physical geographer must be a geologist.

It is, of course, possible to give a general account of the physical geography of a country without entering very fully into details as to its geological structure, as has indeed been done for our own island by Mr. H. J. Mackinder, in his stimulating work on 'Britain & the British Seas'; and, in a simple tract like that of a great portion of the Western Territories of North America, little geological

[1] The reader will find it convenient to peruse that part of the Address which deals mainly with the geological structure of the district, with the aid of the Index-Map of the Geological Survey (Sheets 2 & 5); and the final part, which treats more especially of the physiography, with the aid of the Geological Survey-Maps on the scale of 1 inch and 6 inches to the mile.

knowledge is necessary in order to enable the traveller to comprehend its surface-features. Our own islands are, however, far from simple. Not only do they display a great diversity of rocks of different ages, but the movements which they have undergone are of various dates; and accordingly the geological history of the islands, like its present physiographical condition, is marked by complexity.

With all this complexity there are, as has been long recognized, certain natural divisions. So far as England and Wales are concerned, these are well defined by Dr. H. R. Mill in the map on p. 161 of 'The International Geography.' He there recognizes eleven of these divisions. On the west lie Lakeland, Wales, and Devon & Cornwall; in the centre the Pennine Chain and the Central Plain; and on the east and south the Jurassic Belt, the Chalk, the Weald, the London & Hampshire Basins, and the Fens.

In order to understand fully the present geography of England and Wales, we require a detailed account of each natural division, describing the origin of its scenery. In attempting the account of any one we are more or less concerned with some of the others, and the history of Lakeland is closely connected with that of the Pennine Chain and of parts of the Central Plain.

The present physical features of the district, in addition to its geology, are so well known to our own countrymen that it is not necessary here to give any detailed account of either. A few words will be sufficient to recall the points which are of importance.

Lakeland proper is a highland tract of roughly-circular form, having a diameter of about 35 miles, and composed of Lower Palæozoic rocks. On the south-east side it is connected with the Pennine Chain by an extension of these rocks, forming the elevated tract of the Howgill Fells, near Sedbergh, with a southerly continuation towards Kirkby Lonsdale. Surrounding this central tract of older rocks is a girdle of newer strata, chiefly of Carboniferous age; but, along a small part of the western circumference, beds of New-Red-Sandstone age rest upon the Lower Palæozoic rocks, from St. Bees Head to a point north-west of the estuary of the Duddon. The Pennine Chain runs approximately north and south, and on the north-east is separated from the Lake District by the great depression of the Eden Valley, occupied by New-Red-Sandstone rocks, and trending north-west and south-east from the mouth of the Solway to the town of Kirkby Stephen. A corresponding depression, largely occupied by rocks of the same age, also occurs

on the south-east side of the district forming Morecambe Bay and the lower part of the Lune Valley around Lancaster. The history of these depressed tracts is closely bound up with that of Lakeland itself.

Before entering into particulars with regard to the origin of the central dome and the outlying tracts, it will be well to pay some regard to the writings which bear upon the physical history of the district.

In the 'Lonsdale Magazine' for the year 1820[1] appeared a noteworthy communication entitled 'Remarks on the Succession of Rocks in the District of the Lakes,' by Jonathan Otley. This article was, by degrees, expanded in the various editions of Otley's well-known 'Guide to the Lakes.' I specially call attention to it, for, although Sedgwick fully acknowledged Otley's work as the pioneer of Lake-District geology (thus, in a letter dated September 10th, 1854, and published on p. 249 of the 'Life & Letters of the Rev. Adam Sedgwick,'[2] he writes, 'He was the leader in all we know of the country'), it seems to me that the claims of the humble guide have been largely overlooked, owing to the brilliant powers of the late Woodwardian Professor. It gives me much pleasure to bear testimony from this Chair to the great value of the geological work of a very remarkable man. In the paper to which reference is made, Otley separates the three great groups of the Lower Palæozoic rocks of Lakeland, now known as the Skiddaw Slates, the Borrowdale Series, and the Upper Slates (from the base of the Coniston Limestone to the top of the Kirkby-Moor Flags). The last will, for convenience, be spoken of simply as the Upper Slates, in the succeeding portions of this Address. 'A bed of limestone,' says Otley, 'forms an irregular circle round this mountainous or slaty district, intervening between that and what are called the coal measures,' and he then traces the distribution of this limestone. Otley, therefore, recognized the circular mass of older rock surrounded by the ring of newer strata.

The next important paper connected with our subject appeared in the Quarterly Journal of this Society in 1848.[3] It is by W. Hopkins, and is entitled 'On the Elevation & Denudation of the District of the Lakes of Cumberland and Westmoreland.' In this paper the connexion between the geological structure and the radial drainage

[1] Vol. i, p. 433.

[2] J. W. Clark & T. McK. Hughes, vol. i (1890) 8vo. Cambridge.

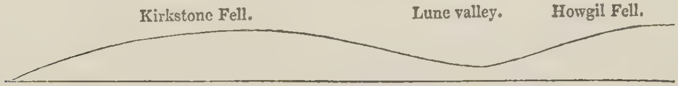
[3] Vol. iv, p. 70.

of the district is discussed. This radial drainage had, by the way, been admirably described many years previously in a 'Topographical Description of the Country of the English Lakes,' by the poet Wordsworth, which appeared first as an essay in a rare work by the Rev. Joseph Wilkinson, was republished with his Sonnets to the Duddon and other poems in 1820, and subsequently in a 'Complete Guide to the Lakes,' published by J. Hudson, of Kendal.

Hopkins argues that a series of dislocations was produced after the deposition of the Lower Palæozoic rocks, and before the deposition of the Carboniferous deposits on their eroded edges; that the surface of these denuded ancient deposits was approximately a plane horizontal surface upon which the Carboniferous rocks were laid down, covering the older rocks; and that, after other movements, the New-Red-Sandstone deposits covered, at any rate, the western and south-western portions of the district. He maintains that subsequently to the formation of the first set of dislocations another set was established, although he fails to find evidence showing the date of production of the second set. The formation of a dome is assigned to a period subsequent to the accumulation of the New Red Sandstone, and the significant remark appears that 'Stainmoor may not have finally emerged from the water till after the Tertiary Period.'[1] It is true that this late emergence seems to be suggested, in order to account for the distribution of the erratic blocks; but the fact that Hopkins believed in the possibility of very late movements in the district is worth noting. The character of the dome is described with great accuracy, and I quote this part of Hopkins's paper at length, reproducing two of his diagrams (*op. cit.* p. 82).

'If we conceive,' says he, 'the surface of junction of the mountain limestone and other formations to be continued . . . . over the central portion of our district, the elevation of this imaginary surface will represent that g e o l o g i c a l e l e v a t i o n which has given to the district its general external configuration, independently of local irregularities. This surface, if seen from a point

Fig. 1.

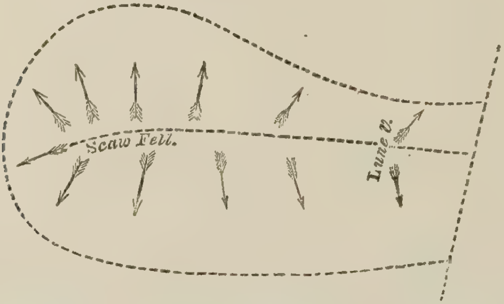


sufficiently distant on the west, would present the appearance of a flat dome; and if seen from the south its outline would resemble that of the annexed diagram [fig. 1], which represents a section along the axis of the district from W.N.W. to E.S.E. Also the form of the area of the district bears a general

[1] *Op. cit.* p. 81.

resemblance to that of the following diagram [fig. 2]; and the dip of our imaginary stratum will be as represented at each point by the arrows. The tendency of this dip between Kirkstone Fell and the valley of the Lune, towards the N.E. on the north of the axis, and to the east of south on the south of the

Fig. 2.



axis, is owing to a declination in the axis itself from Kirkstone Fell to the valley of the Lune, as represented in the former of these diagrams. This, combined with the dip perpendicular to the axis, produces that represented in the figure.'

The dome as represented by Hopkins is, then, an asymmetrical one, formed round an axis running generally east and west. He refers the present drainage to the uplift modified by the dislocations, and the formation of the valleys to denudation. Many of Hopkins's supposed faults are shown, as the result of detailed mapping, to be non-existent; but the general explanation of the drainage which is given in his paper is closely similar to that which has been subsequently offered, and it is clear that to Hopkins we owe the general explanation of the relationship between the dome-shaped uplift and the main radial drainage of the district. To Hopkins's paper I shall recur in a later part of this Address.

In a paper published in the 'Geological Magazine' for 1879[1] by J. Clifton Ward, 'On the Physical History of the English Lake District,' that author also inclines to the view that the Lower Palæozoic rocks of the district were entirely covered by Carboniferous sediment, and that therefore the present land did not come into existence before New Red times.

The late Mr. J. G. Goodchild, in a paper published in 1885,[2] arrived at the same conclusion as did Hopkins, namely, that the uplift of the district was after New Red times.

[1] Dec. ii, vol. vi, pp. 49 & 110.

[2] Trans. Cumberland & Westmorland Assoc. for the Advancement of Lit. & Sci. no. ix [1883–84] 1885, p. 31.

'In no case that has come under my notice,' says he (*op. cit.* p. 37), 'does the dip, or present inclination, of the New Red fall short of the amount of inclination of the surface that rises from beneath it in the direction of the Lake District. The angle of the dip denotes the degree of tilting the rocks have undergone since they were laid down. Depress the inclined surface that rises from beneath the New Red sufficiently to level the newer rock, and you would lower the highest mountains of the Lake District far below the sea-level. In other words, to tilt the New Red to the angle it now lies at, the whole of the central core of Precarboniferous rocks had to be lifted up four or five thousand feet after the New Red was formed. That is to say, the upheaval that caused the tilting is of later date than the New Red.'

In a second paper, on 'The History of the Eden & of some Rivers adjacent,'[1] Mr. Goodchild further argued that the uplift of the Lake District was of Tertiary date, and that prior to this uplift the Cretaceous rocks had extended over the site of the district.

In 1889,[2] being then unaware of Mr. Goodchild's conclusions, I suggested that the uplift which caused the present land-surface might have begun so lately as the Tertiary Period, and that it might be of the nature of a laccolitic dome. I gave further arguments in favour of these suggestions, in a paper on 'The Waterways of English Lakeland,' which appeared in the 'Geographical Journal' for 1896 (vol. vii, p. 602). Some of the views expressed in these papers have also been put forward by Mr. Strahan in the Geological Survey-Memoir treating of 'The Geology of the Country around Kendal, Sedbergh, Bowness, & Tebay' (2nd ed. 1888).

The problems which are attacked in the papers to which allusion has been made are: (i) the nature of the uplift which produced the dome; (ii) the age of the uplift; and (iii) the connexion of the radial drainage with that uplift.

After the drainage was initiated, the production of the present features was largely controlled by the characters of the rocks which now form the central portion of the district; and it is my object to show that the present drainage has been modified owing to these characters, although portions of the early drainage impressed upon rocks newer than the Lower Palæozoic strata may still be detected. The district is comparable to a palimpsest, or, more correctly, might be likened to a tablet once covered with wax, through which lines were impressed by a style, and after the removal of the wax a fresh set of lines has been engraved upon the actual surface of the tablet, which, however, has not completely obliterated the earlier set.

When discussing this portion of my subject I shall have occasion

[1] Trans. Cumb. & Westm. Assoc. no. xiv (1888–89) p. 73.

[2] Geol. Mag. dec. iii, vol. vi, p. 150.

to draw attention, not only to the composition of the rocks (which is responsible for the three different types of scenery marking the tracts occupied by the Skiddaw Slates, the rocks of the Borrowdale Series, and the Upper Slates respectively), but also to certain planes and belts of weakness which are particularly noticeable among the rocks of the Borrowdale Series. These belts are largely due, at any rate, to the movements which affected the district in Devonian times. Their nature, so far as I understand them, has been grasped owing to detailed work among the old rocks, armed with the knowledge supplied by previous writers, and especially owing to the publication of the various maps and memoirs of the Geological Survey. Especially significant are three sets of lines traced in detail upon the Government geological maps, namely: the line which separates the Skiddaw Slates from the Borrowdale Series, chiefly mapped by Clifton Ward; that between the Coniston Flags and the Coniston Grits; and those which cut across and displace the Coniston Limestone, and disappear against the second line. The accurate mapping of these was largely due to W. Talbot Aveline and the surveyors who worked under him.

Of late years the significance of these lines has been impressed upon my colleague Mr. Harker and myself, and a brief sketch of our views with regard to them has been published in a paper entitled 'Notes on the Geology of the English Lake District.'[1] I may be pardoned for stating that the clue to their significance was first obtained by me, as the result of the detailed working-out of the fossil zones of the Stockdale Shales. This work, of a purely-stratigraphical character, in fact, led me directly to prosecute the studies upon the physical history of the district of which the present Address is the outcome, and I mention it to show the importance of detailed geological work to the geographer.

With these brief references to previously-published work, I may now proceed to consider the subject of my Address under the following heads :—

i. Events prior to the uplift which produced the dome.
ii. Production of the dome.
iii. Initiation of the drainage-lines.
iv. Effects of the three types of rock upon the scenery.
v. Modification of the old drainage-lines along shatter-belts.
vi. Depression of the outskirts of the district.
vii. Effects of meteorological conditions: (1) hill-outlines; (2) the Glacial Period.
viii. Conclusion.

[1] Proc. Geol. Assoc. vol. xvi (1900) p. 449.

I. Events prior to the Uplift which produced the Dome.

(a) The Formation of the Lower Palæozoic Rocks.

The formation of these rocks is important, in so far as their lithological characters affect the present features of the district. The division into three main groups—the Skiddaw Slates, Borrowdale Series, and Upper Slates—has already been mentioned, and we need here note only the dominant characters of the rocks of each of these divisions. The thickness of the rocks of the divisions is still doubtful, and only concerns us indirectly. Clifton Ward estimated the thickness of the Skiddaw Slates at 10,000 to 12,000 feet, that of the Borrowdale Series at about 12,000 feet, and that of the Upper Slates at not less than 14,000 feet; and, although other estimates differ considerably from these, the figures here quoted will suffice for our purpose.

The Skiddaw Slates.—The rocks of this group are essentially argillaceous. Massive grits of no great thickness are of little importance in connexion with our present subject; and, although some of the lower beds towards the north-west of the area contain a quantity of arenaceous material through considerable thicknesses of strata, these strata are as a rule finely laminated, differing, so far as their effects upon the surface-features are concerned, in no very marked degree from the more purely-argillaceous deposits. From the physiographical standpoint, general uniformity of character marks the Skiddaw Slates.

The Borrowdale Series.—Not only are the rocks of this series, on the whole, harder than those of the Skiddaw Slates, but there is rapid alternation of more and less resistant bands often of considerable thickness, and it is necessary to pay more attention to the variations in the characters of the rocks. Mr. Harker and I have divided them as follows, in descending order :—

Shap Rhyolites.
Shap Andesites.
Scawfell Banded Ashes and Breccias = Kentmere-Coniston Slate-Band.
Sty-Head Group.[1]
Ullswater Basic Lava-Group = Eycott Group.
Falcon-Crag and Bleaberry-Fell Andesites.

[1] In my 'Notes on the Geology of the English Lake District' (Proc. Geol. Assoc. vol. xvi, 1900), I referred to these rocks under the title 'Garnet-bearing Rocks below the Banded Ashes of Scawfell' as doubtfully intrusive, being

The Falcon-Crag Group,[1] so far as I know, only occurs in force in a roughly-triangular tract lying east of Derwentwater, between that lake and the Thirlmere Valley. The rocks consist usually of rather thin, often vesicular, lavas alternating with ashes; but a few more massive lavas also occur, as well as some thick accumulations of coarse breccia.

The Ullswater Basic Group is more widely spread, forming a very irregular semi-ellipse on the east, north, and west of the Scawfell Ashes of the central group of fells. The lavas are, on the whole, more massive than those of the underlying Falcon-Crag Group, otherwise there is little difference between the rocks of the two groups. The reasons for our identification of the well-known rocks of Eycott Hill with this group are given in brief in the 'Notes' already cited.

The Sty-Head Group has a more restricted distribution, being found chiefly on the north and west, and in a smaller degree on the south of the Scawfell cluster of fells. The rocks, consisting of lavas, ashes, and breccias, are marked by their massive character, although this is no doubt largely due to their subsequent alteration.

The succeeding group occurs in two forms, owing to difference in the type of alteration which they have subsequently undergone. They are essentially pyroclastic, lavas being so scarce that they may here be ignored, and the rocks consist of alternations of finely-laminated volcanic dust and coarser breccias. In the central fells of the Scawfell group, and to a less degree elsewhere, they have been changed into rocks which may be described as hornstones; while, in the band which runs from Coniston to the neighbourhood of Shap, they are well cleaved, and give rise to roofing-slates.

The Shap Andesites are chiefly thin vesicular lavas, interbedded with ashes, and call for no further notice.

The Shap Rhyolites, again, are of little importance to the present subject, save in the neighbourhood of Coniston, where a massive

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misled by the occurrence of some undoubtedly-intrusive rocks of the same general characters in Borrowdale. My colleague Mr. Harker was, I believe, always of the opinion that they were contemporaneous; and the contemporaneous date of the great mass of the rocks lying below the Scawfell Ash-Group has been established beyond doubt by the late E. E. Walker, in his paper 'On the Garnet-bearing & Associated Rocks of the Borrowdale Volcanic Series' (Quart. Journ. Geol. Soc. vol. lx, 1904, p. 70).

[1] A provisional map of the volcanic rocks of the district, by Mr. Harker and myself, will be found appended to the report of the Long Excursion to Keswick, Proc. Geol. Assoc. vol. xvi (1900) pl. xiii, facing p. 526.

rhyolitic breccia—the Yewdale Breccia of Clifton Ward—stands out prominently.

The Buttermere Granophyre and some sills and dykes, chiefly occurring in and around the central fells, are probably of Ordovician age; and the Eskdale Granite may be of that age, though possibly newer.

The Upper Slates.—The sedimentary formations grouped in this division recall, in some respects, the Skiddaw Slates. It is true that there is a greater variation in the lithological characters, as indicated by such names as Coniston Limestone, Coniston Flags, and Coniston Grits; but, owing no doubt to subsequent change, the contrast between the parts marked by flags and grits is not so great as might be expected. As in the case of the Skiddaw Slates, the country is marked by a general uniformity of outline.

(*b*) The Movements at the End of Lower Palæozoic Times and their Effects upon the Rocks.

As it is my object to show that many of the modifications produced in the district, after the initiation of the drainage at a much later period than that which we are now considering, owe their character to the changes produced in the rocks in Old-Red-Sandstone times, it is necessary to pay close attention to the nature of these changes.

So far as the present lie of the older rocks of the area is concerned, the existence of an anticlinal axis running in a general east-north-easterly and west-south-westerly direction through the Skiddaw Slates of the Skiddaw group of fells is a sufficient explanation, for the Borrowdale Series of rocks dips away from the Skiddaw Slates in a general northerly direction north of this fell-group and in a southerly direction south of the group. So far as the district is concerned, this axis is excentric; and accordingly the Borrowdale Series of rocks is soon succeeded unconformably by the Carboniferous rocks on the north, while the latter rocks do not appear on the south until we have traversed many miles of the rocks of the Upper Slate-Group.

But, although this general anticlinal structure explains the present lie of the rocks, there are many complications which produce a marked effect upon the physiography. It is therefore necessary to give an outline of the views of Mr. Harker and myself on the

structure of the area: although, as I have already stated them in the 'Notes' to which reference has been made, the outline may be brief.

It is now generally conceded that the junction between the Skiddaw Slates and the Borrowdale Series of rocks is, in nearly all cases, faulted, and that the fault-plane has an inclination approaching the horizontal. This is abundantly evident from an examination of Clifton Ward's maps, and the low angle of the plane of junction was recognized by Mr. Dakyns so far back as 1869. We have reasons for supposing, however, that this plane is not one of overthrust, but that an overthrust occurs at a lower position; namely, at the base of the Skiddaw Slates, and is therefore but little exposed in the district; although we refer the position of the Drygill Shales of Caradoc age, among the older rocks of the Caldbeck Fells, to the action along this overthrust. According to our views, the rocks of the district have been pushed in a general northerly direction along this plane, and the greatest movement occurred in the Skiddaw Slates; while the rocks of the Borrowdale Series, though moving northward, lagged behind the Skiddaw Slates, and the Upper Slates in turn lagged behind the rocks of the Borrowdale Series. We have, therefore, described the fault which separates the Skiddaw Slates from the Borrowdale Series of rocks, and another with higher inclination which we believe to occur between the Borrowdale Series of rocks and the Upper Slates, as 'lag-faults.' So far as the present physical features are concerned, the question as to whether these faults are overthrusts or lag-faults is unimportant. The part played by another set of faults, to which we referred as 'tear-faults,' in controlling the production of some of the physical features of the district is, on the contrary, of very great import; and some attention must here be devoted to the nature and extent of these 'tear-faults,' which appear to correspond with the blätter of Suess.

One may regard the rocks of the three divisions as three strips moving onward during the period of earth-movements, and each of these strips is divisible into minor bands, which are specially marked in the case of the rocks of the Borrowdale Series and of the Upper Slate-Group. But different parts of the same strip moved at different rates, and where the rocks were too rigid to adapt themselves to the different rates by bending, one portion of a strip

was torn away from the other along these tear-belts. Evidence of this action is given in my 'Notes,' in the case of the well-marked faults which affect the Coniston Limestone between Windermere and Coniston Lakes; but perhaps the most striking proof of the existence of these 'tears' is furnished by the outcrop of the Armboth dyke between Borrowdale and Thirlmere. This dyke is seen to be vertical on Fisher Crag. A tear-fault runs along Fisher Gill which shifts the dyke for nearly a quarter of a mile to the north-east, and a similar shift is caused by another tear along Middlestead Gill.

With such a movement as that above noticed a simple straight cut is unlikely to occur; the action really is more akin to a tearing of the rocks, and accordingly the tear-faults are usually belts of much broken rock.

In my paper on 'The Waterways of English Lakeland,'[1] I described in detail one of these belts in Troutbeck, which, as the result of detailed mapping of the zones of the Stockdale Shales, was found to be occupied by a series of faults of different sizes cutting the rocks into blocks so as to form a gigantic fault-breccia. Of such a belt of broken rock, produced by horizontal, or nearly horizontal, movement in a more or less vertical plane, I propose to speak for convenience as a 'shatter-belt.' Although many of these shatter-belts occur along the lines of 'tear-faults,' it must not be supposed that permanent displacement of the rocks at the sides accompanies all or even the majority of the belts. Many of them show no signs of faulting, and were probably produced by temporary movement, which, on its cessation, left the rocks in their original positions. I propose to discuss later the importance of these shatter-belts in producing modifications of the surface-features. At present, I confine myself to an account of their characters and general distribution.

In the paper referred to above I suggested that the 'cleft of Dunmail Raise and the valleys of Thirlmere and Grasmere, which run north and south from that cleft, are apparently due to a belt of shattered rock,'[2] and stated that I was led to believe that many of the minor valleys of the volcanic tract of the Borrowdale Series had been formed along similar belts, and not along simple fractures. Since this paper was written I have paid more attention to these belts, and find it easy to recognize them in the volcanic tract, where they are very abundant and of varying width and length.

[1] Geogr. Journ. vol. vii (1896) p. 602.
[2] *Op. cit.* p. 612.

More than once have the Lower Palæozoic rocks of portions of the district been covered by red sandstones, and waters impregnated with iron-peroxide have filtered into the older rocks beneath. Where these rocks are comparatively unbroken hæmatite-staining usually occurs as a mere film on joint-planes; but where extensive fracture has taken place along 'lags' or 'tears,' the rocks of the fractured belts are generally more or less stained throughout with hæmatite. Accordingly, when extensive hæmatite-staining is observed, a fault of the lag or tear-type may be suspected. The lowly-inclined lag-fault material does not, as a general rule, produce any marked feature, whereas the vertical or highly-inclined shatter-belts of the tear-faults are readily affected by denuding agents, and are very frequently (as will be ultimately seen) occupied by gorges or portions of large valleys. On examining the tract occupied by these gorges, the rocks between one gorge and another are frequently found to be fresh and unstained; while the raddled rock of the gorges is seen to be shattered by innumerable fissures, large and small. Nowhere is this more clearly seen than on the small plateau of the Scawfell region which lies north of Great End, known as Seathwaite Fell, on which are situate Sprinkling Tarn and a number of minor pools. The more or less flinty banded ashes of this Fell, dipping at a low angle, run in unbroken scarps of hard rock for some distance, when they suddenly change on the appearance of one of the shatter-belts. Two marked sets of these belts here run approximately at right angles. One, to be noticed more fully later, is marked by the upper part of Ruddy Gill draining into Grainsgill, and farther west by the stream which flows into Sty-Head Tarn. This belt has a general west-north-westerly and east-south-easterly direction.

Along a belt belonging to the other set, which runs from south-south-west to north-north-east, is a lower portion of the Ruddy-Gill stream. Nothing can be more marked than the contrast between the bare grey crags of the plateau and the shattered rocks of this portion of Ruddy Gill, glowing purple-red, and setting off to advantage the rich greens of the ferns, bilberry, Alpine ladies' mantle, rose-root, and kidney-leaved sorrel, which flourish in the rich soil of this easily-disintegrated belt.

Let us pass on now to a consideration of the distribution of these belts. Minor belts seem to be generally distributed throughout the Lower Palæozoic rocks of the district, but there are three very

important ones, the extent of which must be more particularly noticed. The first of these seems to terminate on the east in Great Langdale, near the tarn of Elterwater. In a westerly direction it is traceable up Little Langdale, and over Wrynose Pass across the Duddon Valley, and thence over Hardknott. It then runs along part of the Eskdale Valley to Eskdale Green, and passes over a depression north of Muncaster Fell to Miterdale, where it is lost in the alluvium along the lower part of that valley. This belt has an east-north-easterly to west-south-westerly trend, and the total distance along which it is traceable is about 15 miles. The character of the rocks in this belt is well shown in Wrynose and Hardknott passes.

The second belt has already been briefly mentioned as running through Dunmail Raise. It seems to start from near the eastern termination of the belt described above, and runs towards the north-north-west. Tracing it northwards from Great Langdale, it passes through the depression of Red Bank between Langdale and Grasmere, thence up the Grasmere Valley to Dunmail Raise, down the Thirlmere Valley and along Naddle Beck, and is probably continued through the Skiddaw Slates of the Glenderaterra Valley between Skiddaw and Saddleback, along a total distance of nearly 20 miles.

The third belt leaves the first at a point about 4 miles west of that from which the second diverges, namely, near Little Langdale Tarn. Thence it is traceable north-westward through a depression on the north side of Lingmoor above Blea-Tarn House (where the feature caused by it was pointed out to me some years ago by Lord Avebury), and over the col into Great Langdale, thence up the Mickleden fork of that valley, over Rossett Gill, past Angle, Sprinkling, and Sty-Head Tarns (where it has already been noticed), through Windy Gap between Great and Green Gable and thence down a stream which forms one of the headwaters of the Ennerdale drainage. Its total length is about 11 miles.

Of the minor belts, those most readily studied are among the great mass of highly-altered ashes and breccias of the Scawfell Group in the central fells, Scawfell and its neighbours. Probably they are actually more numerous here, owing to the greater rigidity of the rocks of this tract than of those of others ; but they are also more easy to detect, owing to the marked contrast between the rotten rocks of the belts and the fresh unweathered rocks of the interspaces between belt and belt.

As regards their age, the evidence is in favour of the greater number having been produced in Devonian times. The more easy detection of those in the centre of the district might be regarded as a proof that they were actually more abundant there, and that they were produced, during the later movements which caused the dome, as radial cracks from the centre; but they do not appear to have any radial arrangement. On the contrary, the more usual trends are in two directions roughly at right angles, namely, about north-north-west to south-south-east and east-north-east to west-south-west, corresponding with the general dip and strike of the Lower Palæozoic rocks produced in Devonian times; while the three dominant belts, the trend of which has been noticed in detail, radiate from a tract where the strike of the rock changes rather abruptly from east-north-east and west-south-west to north-east and south-west.

Detailed examination of some of the belts shows that the fracture of the rock was often accompanied by other changes, similar to those which can be proved to have taken place in Devonian times. A well-marked belt runs up Raise Gill to the east of Watendlath Tarn. The rocks along this have been, in some cases, crushed into a mylonitic mass, the porphyritic felspars being flattened into flaky patches; cleavage-planes have been formed, and these in places chevron-folded; and a development of sericitic mica has been set up along the planes.

The evidence, then, is in favour of the bulk of these shatter-belts being along tear-faults. Most of the mineral lodes inserted on the maps of the Geological Survey have been formed along these belts, though occasionally a lode is found along the more horizontal lag-faults. But an examination of the lodes on the map gives a good idea of the general distribution of the shatter-belts, though, of course, a large proportion of the belts do not contain sufficient ore to allow of their representation as lodes.

Owing to the lag- and tear-faults the district is cut up into blocks of rock of a more or less rhomboidal nature. These rhomboidal blocks are of all sizes, from masses several miles long to the fragments of an incipient fault-breccia. In the case of the breccias rounding has often gone on to such an extent as to produce fault-conglomerates; and the same seems to have been produced on a somewhat larger scale, leaving 'eyes' of hard rock surrounded by broken material. Hence, it is only where the rocks have been slightly affected by movement (as in the Eycott Group on the north

of the anticline and in the Falcon-Crag Group on the south), or where the rocks have been exceptionally resistant, that continuous outcrops are traceable. Elsewhere the outcrops often occur in eye-like patches surrounded by vegetation.

Of other changes which took place during this period little need be said. It has already been stated that the Ennerdale Granophyre and perhaps the Eskdale Granite are apparently of the age of the Borrowdale Group. Igneous rocks were certainly forced among the Lower Palæozoic rocks in Devonian times—for instance, the granites of Skiddaw and Shap; but the exposed area of these rocks and of the rocks which have been affected by their metamorphism is too small to produce much effect upon the present physiography.

The wide distribution of the cleavage impressed on the old rocks of the district in Devonian times is well known. Along two belts it is especially prominent, and in the northerly belt especially it is somewhat oblique to the strike of the beds. Each belt is in the rocks of the Borrowdale Series. The northerly one begins just east of Borrowdale near Lowdore, passes through Castle Crag over Scawdel and through Honister Crag. The southerly one is much more extensive: starting in Wet Sleddale near Shap, it crosses the valleys of Long Sleddale, Kentmere, and Troutbeck, past Rydal and the Langdale valleys, Tilberthwaite, and the summit of Coniston Old Man, to die out in the Duddon Valley. Important as these belts are geologically, the rocks in them do not profoundly affect the physical geography of the district. Here and there depressions have been worn along them, but they usually traverse hill and dale alike, as is well seen in the Coniston group of fells.

The date of the peculiarly-flinty type of alteration which affects the rocks of the Scawfell group of fells is not yet determined, nor has the cause of the alteration been actually settled. The occurrence of violently-folded structures and brecciation in the banded ashes of these flinty rocks and of the slate-belts alike, and their similarity to structures in some of the Upper Slates, points to the folding and fracture being in the three cases post-Silurian; and as this folding and fracture certainly occurred before the flinty alteration of the rocks, the probability is that this alteration is also post-Silurian. Whatever its date, its occurrence is very important in determining the detailed structure of the Scawfell group of fells.

It is well known that, during the period of the Devonian movements, the rocks of the Lake District were subjected to extensive

denudation, with the consequence that the Upper Palæozoic rocks rest upon the upturned and eroded edges of the older rocks, overlapping them to rest on rocks of all ages—from Arenig to Upper Ludlow. The amount of material removed from the centre of the arch at this period must have been over 20,000, nay, perhaps over 30,000 feet.

That the surface was for some time uneven is probably indicated by the sudden expansion of the Old-Red-Sandstone rocks in the neighbourhood of Ullswater, which (as has been suggested by many writers) were probably deposited in an old valley.[1] But, as the result of continuous erosion and the filling-in of the deeper depressions by the Old Red Conglomerate, a comparatively-level surface was produced, which is still marked along the Pennine Chain east of Appleby, and especially in the Ingleborough district, where it has not been affected by the later movement that produced the Lake-District dome. The former general evenness of the surface in the Lake District itself is indicated by the very gradual changes in the level of the old basement-plane between Carboniferous and older rocks, changes which coincide with those in the inclination of the Carboniferous strata themselves.

(c) The Formation of the Carboniferous Rocks.

As bearing upon the question of the former extension of Carboniferous rocks over the site of the Lake District, the existence of a group of rocks on the eastern side of the district of earlier age than the basement-rocks found in the Ingleborough area is of interest. The Shap Limestone there occurs below the Knipe-Scar Limestone, which (with some higher beds) is referred by the officers of the Geological Survey to the Melmerby-Scar Limestone, in turn

[1] I speak of these rocks as Old Red Sandstone, the geological group to which they were assigned by the earlier writers on the district. It has recently become the fashion to term them basement Carboniferous. In the absence of fossils the exact date cannot be determined, but the rapid changes in their thickness, and especially the occurrence of another unconformity above them, marked by the existence of a conglomerate-rock with quartz-pebbles, whereas the conglomerates of the Old Red are polygenetic (composed of pebbles of Silurian grits, and more rarely limestones and volcanic rocks and Skiddaw Slate), suggest that some time elapsed between the formation of these rocks and the true basal Carboniferous deposits. Their lithological characters are certainly suggestive of Old Red Sandstone, and physically the base of the old Carboniferous plane is connected with the quartz-pebble-bearing conglomerate and not with that of the polygenetic conglomerate.

correlated with the Lower Scar Limestone of Ingleborough, the basal Carboniferous deposit over the greater part of that region.

Study of the fossils by Prof. Garwood bears out this view. It would seem, then, that so far from the Lake District having been an island in early Carboniferous times, its eastern part, at any rate, was submerged before the tract of land lying farther to the east and south.

Upon these early beds were deposited the great mass of Lower Carboniferous rocks, consisting of limestones and shales, and subsequently the Millstone Grit and Coal-Measures of Upper Carboniferous times. Had the district existed as land during the deposition of the Lower Carboniferous beds, one would certainly expect to find more detrital material in these rocks surrounding the district than is actually the case.

(*d*) The Movements at the End of Carboniferous Times and Accumulation of the Permo-Triassic Rocks.

Ere the deposition of any Permian rocks in the North of England, upheaval and denudation took place through Permo-Carboniferous times (and probably also during the closing stages of the Carboniferous Period), and profoundly affected the conditions in the Lakeland area. The earth-movement gave rise to the Pennine anticline with its general north-and-south trend, and to the complex anticline with an east-and-west axis passing through North Lancashire and North-West Yorkshire. As the result of these movements and the accompanying denudation, the Lower Carboniferous rocks of Northern England were arranged in a cruciform manner, with coalfields between the arms of the cross—the Northumbrian field on the north-east, that of Yorkshire, Derbyshire, and Nottinghamshire on the south-east, that of Lancashire and North Staffordshire on the south-west, and that of Cumberland on the north-west. The movement was (at first) no doubt chiefly responsible for the production of folding of the strata, although even then subsidiary faulting probably occurred; but there is still a difference of opinion as to the period of important movement along the lines of the great faults which are found in the neighbourhood of Lakeland.

About the period of deposition of the earliest Permian rocks of the area faulting became an important factor, and the North of England seems to have been cut up into blocks with the depressions,

in which the New-Red-Sandstone deposits were at first mainly formed, abutting against the block-hills. Prof. P. F. Kendall has given evidence of the nature of the movement along the Pennine fault in Permian times.[1] So far as the Northern Pennines are concerned the fold was of the nature of a very asymmetrical arch and trough with a steep middle limb inclined to the west, from the top of which the strata dipped eastward at a gentle angle and from the base of which they rose also at a gentle angle to the west. Along the Pennine fold the Lower Palæozoic rocks of the Crossfell Inlier may, as Prof. Kendall suggests, have been exposed by denudation. West of the Lake District they certainly were so exposed in Triassic times, as shown by the present repose of rocks of that age on the Lower Palæozoic rocks between St. Bees and the country north-west of the Duddon estuary.

Throughout Permo-Triassic times movement may have taken place along the Pennine, Dent, and Craven Faults—in the case of the first two in connexion with the north-and-south Pennine axis, and in that of the third in connexion with the axis which runs east and west. That movement did take place along the Pennine and Craven Faults after the deposition of the Permian rocks is shown by the fact that these rocks abut against the Carboniferous along the Pennine Fault, and also along the Craven Fault near Ingleton; while the abrupt truncation of the Dent Fault by the Craven Fault indicates that the formation of the former was anterior to that of the latter.

Notwithstanding these movements, it is very doubtful whether any portion of the Lake District or of the Pennine Chain projected above the Permo-Triassic rocks at the end of Permo-Triassic times, for we have seen that the evidence furnished by the lithological characters and the present dip of the Carboniferous rocks indicates that they once extended over the district, as argued by Hopkins; and where these Carboniferous rocks were removed by denudation along the western margin of the district between St. Bees and the Duddon estuary in pre-Triassic times, the dip of the Triassic rocks (if continued eastward) would carry them over the district, as was also argued by Hopkins. There seems every reason to suppose that, at the close of the Triassic Period, the Lower Palæozoic rocks of Lakeland were buried beneath a cover of newer rocks of Carboniferous age and New-Red-Sandstone age. There certainly

[1] Rep. Brit Assoc. 1902 (Belfast) p. 604, & Geol. Mag. dec. iv, vol. ix (1902) p. 510.

appears to be no evidence pointing to the formation of the dome in Triassic times. Indeed, the probability is that the whole of the North of England was covered with Triassic rocks at the end of that time. The similarity between the Triassic rocks on the two sides of the Pennine Chain is sufficient to indicate that they were formed under very similar conditions and in one physiographical region. I shall eventually argue that important movement took place along the Pennine Fault in post-Triassic times, sufficient to elevate the Pennine Carboniferous rocks into a ridge, of which the present chain is the relic. If this ridge were depressed to the level which it occupied before the later faulting, a comparatively-level tract would be produced, over which the Triassic rocks might well have extended.

II. Production of the Dome.

In discussing the changes which occurred in and around our area during the deposition of the Jurassic, Cretaceous, and Eocene rocks of Britain, it is necessary to pay regard to some of the features presented by areas somewhat remote from that which we are specially considering.

Leaving out of account the east-and-west strike of the Mesozoic rocks of East Yorkshire, the rocks of this date east of the Pennine Chain have a north-and-south strike with an easterly dip, the strike being parallel with that of the axis of the Pennine Chain itself. They have been described by Prof. W. M. Davis as giving rise to a coastal plain abutting against the Pennine Chain. But I can find no evidence of the existence of this chain when they were deposited. If it existed, the dip should be due, not to earth-movement, but to deposition along a sloping shore falling eastward; in which case the deposits should show distinct indications of an approach to land when traced westward. Surely, for instance, the Chalk would have some of the detrital matter derived from the Pennine Chain. But, even if this were not the case, the evidence is all in favour of the dip of these rocks being due to subsequent movement, and not to deposition on a sea-floor sloping eastward. Now, the junction between the Trias and the Lias near Middlesborough is about 40 miles distant from the watershed of the Pennine Chain immediately to its west. If we suppose that the dip of the plane separating the Lias from the Trias is only 1°, and restore the old surface to the west, assuming that the dip still remains at 1°, this would carry the position of the plane above the watershed of the Pennines to a vertical height of nearly a mile above sea-level.

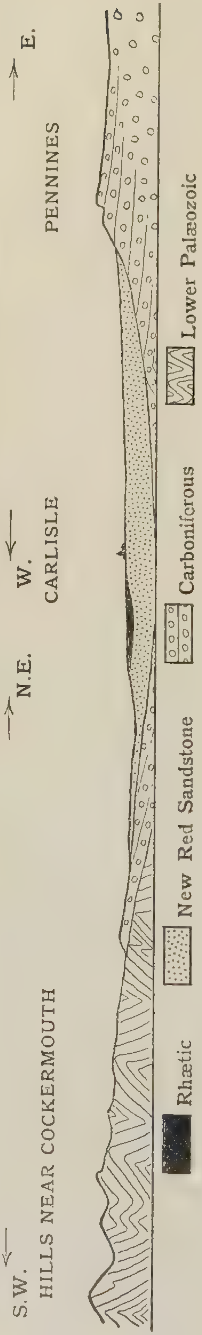


Fig. 3.—*Diagrammatic section across Edenside, from the north of the Lake District to the Pennine range.* (*See p. lxxxvii.*)

Assuming, therefore, that the plane of deposit of the Rhætic beds was originally horizontal, the junction between Rhætic and Triassic rocks, if they had been affected by uplift in one direction and no denudation had taken place, would be high above sea-level near Carlisle. Nevertheless, we actually find Rhætic deposits to the west of Carlisle nearly at sea-level. How did they get there? In order to answer this question, let us consider the outcrop of the Rhætic in the northern part of our island. The outcrop, on the whole, passes southward from near Middlesborough through Yorkshire, Lincolnshire, and Leicestershire, parallel to the trend of the Pennines. But, on the other side of the Pennines, almost due south of the Carlisle outlier of Rhætic deposits, is another occupying a tract of country east of Wem and Whitchurch in Shropshire; and these outliers occur in the tract of country which, apart from the Lake-District dome, is occupied by a continuous belt of New-Red-Sandstone rock.

If, then, the rocks of these outliers were originally deposited at the same level as the contemporaneous rocks of the main outcrop, and as they are still much at the level of the rocks of that outcrop, the original plane on which the Rhætics were deposited must have been deformed by an anticlinal fold, or by a fault, to carry part of it over the present top of the Pennine range.

The St. Bees Sandstone abuts against the Lower Palæozoic and Carboniferous rocks at the Pennine Fault; so there has evidently been movement along that fault since the formation of the St. Bees

Sandstone, letting down the newer rocks of Edenside on the downthrow side to the west of the fracture. This fault, which is seen to be partly of a date subsequent to the accumulation of the St. Bees Sandstone, would, if it had undergone movement in post-Rhætic times, account for the existence of the Rhætic outlier to the west of Carlisle.

Let us now consider the Lake-District rocks in relationship to this Rhætic outlier. A section drawn in a north-easterly direction, from the Lake-District Fells near Crummock across the Rhætic outlier of Carlisle, and then east to the Pennine Chain, is reproduced in fig. 3 (p. lxxxvi). Leaving the faults out of consideration, for they are but subsidiary to the folds, the rocks of Edenside[1] lie in a syncline between the older rocks of the Pennine Chain and of Lakeland, the newest rocks of the syncline being the Rhætic deposits to which reference has been made. The folding, therefore, is in part post-Rhætic. But the north-eastern slopes of the Lake District form the middle limb common to the Edenside syncline and the Lake-District dome: consequently the age of the uplift which formed the dome is, in part at any rate, post-Rhætic.

These Rhætic rocks elsewhere in Britain are succeeded by the whole of the deposits of the Jurassic System, formed at a time during which there is no evidence of great movements in the British area such as would have formed the dome. The only marked break in Britain among the Mesozoic rocks above the Rhætic beds is that of Middle Cretaceous times. The uplift, then, might have occurred in the Middle Cretaceous period. But the lie of the Chalk in the North-East of Ireland and in Yorkshire respectively seems to necessitate the formation of an intervening anticline in times subsequent to the Chalk. In fact, the arguments previously advanced in the case of the Rhætic strata on opposite sides of the Pennines apply also to the Chalk, which probably occupies part of the Irish Sea, as suggested by the abundant chalk-flints which were dispersed southward in Glacial times.

Again, the uplift at the end of Cretaceous times over our islands does not appear to have given rise to great elevations, the unconformity between Cretaceous and Eocene rocks when seen being somewhat trivial. It is quite possible, therefore, that what is now the Lake District and adjoining country was at one time covered by rocks of later Mesozoic and early Tertiary age, for the great move-

[1] A term used by the late Mr. J. G. Goodchild for the physiographic lowlands between the Lake-District and Pennine uplands, of which the actual Eden Valley forms but a portion.

ments which produced so marked an effect upon Britain culminated, as generally recognized, in Miocene times. This I believe to have been the date of the uplift which formed the Lake-District dome, and I propose to put forward reasons other than those above advanced in favour of this.

Let us for the moment consider the geology of England as a whole. As I have elsewhere remarked,

'the shape of England is roughly an isosceles triangle with a base extending from Northumberland to Cornwall and the apex on the coast of Kent. The position of the base is due to the uplift of Palæozoic rocks, to the west and north of England, whilst the position of the two sides is owing to the strike of the Mesozoic and later rocks, with a general northerly trend to the north and a westerly trend to the south,' [1]

the portion of the island next the apex being, in fact, composed of Mesozoic rocks, with a mean strike parallel to the direction of the base.

'Examination of the geology of England in fact indicates that had the Miocene tilt been in an opposite direction, giving the newer strata a [north] westerly dip instead of a [south] easterly one, the Highlands of Britain would be on the [south] east side, the Mesozoic rocks would be denuded there, and the London ridge and similar ridges now buried beneath newer deposits would form a hilly country occupied by the more ancient formations, whilst the [North and] West of England, and possibly Scotland and Ireland, would consist of low ground formed of a peneplain of old rocks, or more probably of Triassic beds and even later deposits, possibly as modern as the Cretaceous and Eocene beds.' (*Op. cit.* p. 280.)

Prof. Judd, after describing the present distribution of the newer rocks of Western Scotland, remarks:

'In the face of these facts, I believe that is impossible to avoid the conclusion that the whole of the north and north-western portions of the British Archipelago—now sculptured by denudation into a rugged mountain-land—were, like the south and south-eastern parts of the same islands, to a great extent, if not completely, covered by sedimentary deposits, ranging in age from the Carboniferous to the Cretaceous inclusive; and that, as a consequence, we must refer the production of the striking and very characteristic features of those Highland districts to the last great epoch of the earth's history—the Tertiary—and very largely indeed to the latest portion of that epoch, namely the Pliocene.' [2]

I pass now to another line of argument. Let us compare the

[1] 'The Development of British Scenery' Science Progress, vol. vii (1898) p. 285.

[2] 'The Secondary Rocks of Scotland.—III: The Strata of the Western Coast & Islands' Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 669.

Lake District with Skye. In each case the hard rocks which now form those tracts must have been covered by softer or more easily-denuded rocks: in the case of the Lake District certainly rocks of Carboniferous age and New-Red-Sandstone age, in that of Skye the rocks into which the great intrusive masses were forced. In Skye the Cuillin Hills have several summits rising over 3000 feet, and the tract has been deeply trenched by streams cutting into the hard rocks of the district, although the erosion in this case has been in operation only during the latter part of Tertiary times.

The Lake-District hills also rise in a few cases to a height of over 3000 feet. The courses of the streams in this case, it is true, are longer than those of Skye, the shortest being about three times the length of the streams flowing from the Cuillins, while others are longer; and accordingly the deepening, in so far as it depends upon grade, would be slower in the Lake District than in Skye. In opposition to this it must be noticed that the covering of rocks was probably more resistant in Skye than in the Lake District; and the intrusive masses of the former district are certainly much more resistant than those of some of the highest elevations of the latter, as, for example, the Skiddaw Slates of Skiddaw. If, then, the Skye uplift can have been sculptured into its present condition in late Tertiary times, it seems to me that the same explanation applies to Lakeland; and that if we suppose Lakeland to have existed as land since, say, the end of New-Red-Sandstone times, it would long ago have been reduced to a nearly-level surface by denuding agencies: whereas, although the main streams have largely reached base-level, this is far from being the case with the minor streams, and great tracts of plateaux occur between the main valleys which have hardly been touched by stream-erosion of the older rocks. This erosion is still going on. The streams which course over the Skiddaw Slates are turbid with sediment after heavy rains, although, for a reason to be considered later, the streams which run through the volcanic rocks are as a rule fairly clear even after heavy rains. But even there erosion takes place during those exceptionally-violent falls of rain which produce the greatest effects, witness the occurrence in the Vale of St. John on August 22nd, 1749, when (as described by Gilpin) a stream forced a new channel through solid rock, and made a chasm at least 10 feet wide.

Physiographically, then, the district is comparatively young, and study of its physiographical features bears out the conclusions attained after study of its geological structure.

Again, the nature of the dome is in itself suggestive. As I have elsewhere remarked,

'regular dome-shaped uplifts, having a symmetry like that possessed by the Lake-District dome, are produced, as far as we know with certainty, in one way only, by intrusion of a lenticular mass of igneous matter beneath, forming a laccolite. Subsequent to the deposition of the New Red Sandstone of Britain, we have no evidence of intrusion of igneous rock until early Tertiary times, when the intrusions of plutonic rock occurred in Skye, Rum, Ardnamurchan, Mull, and Arran, in a line which, if continued southwards, would pass beneath the Lake District.'[1]

I quote this remark here, as in some degree corroborative evidence in favour of the suggestion of the Tertiary date of the uplift. To the nature of the dome I shall have occasion to refer more fully presently.

The actual age of the uplift is only important in a subsidiary degree to the subject under consideration. My main object is to show the effect on the present physical structure of two important sets of movements, of which one occurred in Devonian times and the other later, almost certainly after the deposition of the New-Red-Sandstone rocks, possibly (I think, probably) in Tertiary times.

Let us now pass to a consideration of the characters of the dome-shaped uplift and the effects of accompanying movements, in illustration of which a sketch-map is appended (fig. 4, p. xci).

The high ground of the North of England is determined mainly by the Pennine anticline and by the Lake-District dome; and I have argued that the final and, so far as we are concerned, important differential movements which affected the topography of the north were geologically contemporaneous.

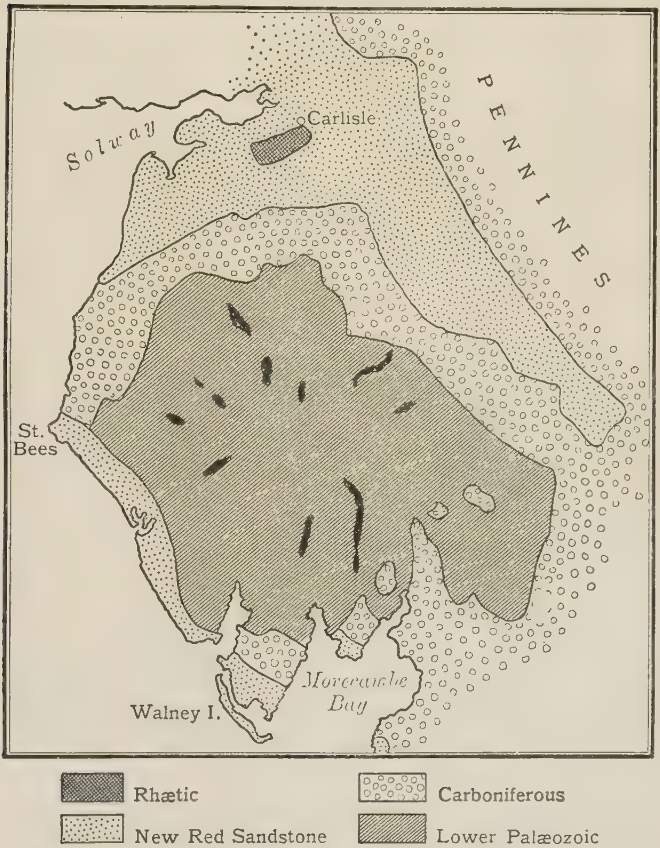
The general axis of the Pennine Chain was north and south, and, with such an axis and a symmetrical dome on the west, we should find either a circumference of New-Red-Sandstone rocks running round the dome; or, if the dome on the east touched the Pennine uplift, the newer rocks would be there absent, and the Carboniferous rocks of the margin of the dome would be continuous with those of the Pennine Chain.

There is a tract on the east, marked by the absence of New-Red-Sandstone rocks (which elsewhere surround the dome), extending from Kirkby Stephen on the north to the neighbourhood

[1] 'The Waterways of English Lakeland' Geogr. Journ. vol. vii (1896) p. 604.

of Lancaster on the south; and accordingly, instead of having a ring of Trias[1] surrounding the district, we have a **C**-shaped mass, with the northern horn of the crescent extending much more to

Fig. 4.—*Geological sketch-map of the Lake District and the neighbouring region, on the scale of 10 miles to the inch approximately.*



[The principal lakes are shown in black, and roughly indicate the directions of the lines of radial drainage.]

the south than the southern horn does to the north. South-west of this break in the girdle of newer rocks, the symmetry of the dome is

[1] It is true that there is a little patch of Permian at Westhouse near Ingleton, let down by the Craven Fault, but this does not affect the argument.

affected by the great mass of Lower Palæozoic rocks of the Howgill and Kirkby-Lonsdale Fells and the Carboniferous highland to the east of those Fells. We have here, so far as the country occupied by Lower Palæozoic rocks is concerned, a semi-dome bounded on the east by the Dent Fault, and separated from the main dome by a nearly-semicircular ring of Carboniferous Limestone which extends in a curve from Kirkby Lonsdale to Kendal, where it becomes broken; but two outliers between Kendal and Tebay mark its course, and at Tebay it again runs continuously in an easterly direction to join the Dent Fault south-east of Ravenstonedale.

This subsidiary dome affects the symmetry of the uplift, and also the distribution of the low ground occupied by Triassic rocks, which forms Edenside on the north-east of the district and Morecambe Bay on the south-east; for the occupation of, at any rate, a large part of that bay by Triassic strata is shown by their occurrence on the west side of the bay around Barrow-in-Furness, on the north side near Cartmell, and on the east side near Heysham.

Before considering further the subsidiary dome we may turn to the main dome, occupied largely by the Lower Palæozoic rocks of the Lake District proper; and, in the first place, let us trace the line of junction between the Lower Palæozoic and the newer rocks around the main dome.

Beginning at the town of Cockermouth, on the north of the district, this line extends in a general easterly direction to Carrock Fell, and thence south-eastward to Tebay, where the break above described is found; but, taking the line in the direction of the outliers, the trend is here south-westward past Kendal to Cartmell, then westward through Ulverston to the north of Dalton-in-Furness, across the estuary of the Duddon to Millom, thence north-north-westward to Egremont, and finally north north-eastward to Cockermouth.

The line corresponds generally with the circle having a radius of 15 miles, drawn by Dr. H. R. Mill from

'what was possibly the crown of the ancient dome, and is now the middle of the small central mountain-mass lying between the Thirlmere-Windermere and the Langstrath-Borrowdale depressions.' [1]

It must be remembered, however, that the circular line is not

[1] 'Bathymetrical Survey of the English Lakes Geogr. Journ. vol. vi (1895) p. 48.

horizontal, but runs, on the whole, at higher elevations on the north and north-east than on the south and west. If denudation were to cut back the junction until it were everywhere at a uniform height above sea-level, the rim would lie farther north and north-east than it does at present, although no very profound change in the outcrop of the line of junction would be thus produced.

The symmetry is more apparent on the map than in reality. Generally speaking, the ground rises as we approach the imagined centre of uplift; but there are exceptions, the principal being the masses of high ground around Skiddaw north of the centre, and Helvellyn north-east of it. The Skiddaw elevation suggests a subsidiary dome, a point which will be considered when the drainage is described; while the Helvellyn elevation could be accounted for as the result of later movement along the old line of fracture through Grasmere and Thirlmere (which has been previously described), or it may be simply due to the fact that, geologically, the dome is not one which could be circumscribed by a circle, but, as maintained by Hopkins, is rather of the nature of an ellipse, of which the major axis would run through the Helvellyn mass.

Another departure from symmetry is noticeable south of the dome. From Millom around the northern margin, and thence as far south as Tebay, the line of junction between the Lower Palæozoic and the later rocks is comparatively regular; but at the southern end, between Kendal and Millom, the Carboniferous rocks are let down against the Lower Palæozoic in great wedges, the apices of which point on the whole northward. That these wedges are partly due to early faulting is manifest, but subsequent movement has possibly affected them. Their importance to us consists in the determination of a series of estuaries along the tracts occupied by the newer rocks, namely, those of the Kent and Gilpin, the Winster, the Leven, and the Duddon.

The uplift which gave rise to the Lake District did not, then, produce a simple symmetrical dome, but one main dome of a slightly-elliptical form, or rather, I would say, a form approaching that of a short-handled spoon, like an old 'caddy-spoon,' with the handle to the east; a subsidiary dome occupying the site of the Howgill and Kirkby-Lonsdale Fells and the fells to the east of these; and perhaps a minor and more symmetrical dome in the Skiddaw tract.

Such dome-clusters are found among the plateaux of the Colorado

region, as laccolites, apparently connected with the block-structure which the plateaux themselves exhibit.

That a large area of Scotland, the North-East of Ireland, and the North of England, formed such plateaux in Tertiary times is suggested by many structural features; and the idea that laccolitic uplifts occurred is in accordance with our present views concerning the origin of the great intrusive masses of Western Scotland.

In connexion with this point, I would call attention to the striking similarities between the igneous rocks of the Carrock-Fell complex and those of Tertiary date in Scotland. These rocks and the olivine-bearing rocks of the Skiddaw tract are unlike any other igneous rocks of the district; and it is interesting to find them in the tract, the drainage of which, as will be presently noted, suggests a subsidiary uplift.

If the dome was produced by the intrusion of igneous rock, it is a question of interest as to what horizon was occupied by this igneous rock.

I have elsewhere argued that the lag-faults and tear-faults which affect the Lower Palæozoic rocks were subsidiary to a great overthrust beneath the Skiddaw Slates, which caused these slates to be pushed northward over a series of newer rocks. Such a thrust-plane would serve as a plane of weakness, along which igneous matter might be easily injected; and it is interesting to find that the Carrock intrusion occurs at the junction between the Skiddaw Slates and the newer Drygill Shales, which, as I have suggested, may lie beneath the supposed overthrust. In that case the dome would not possess a horizontal base, but one inclined towards the south. I am not aware of any evidence furnished by the shape of the dome or the nature of the drainage which tells for or against this view, unless it be the fact that the newer rocks on the south rapidly pass below sea-level in Morecambe Bay; whereas on the north a considerable tract of high ground is occupied by Carboniferous rocks, and the New Red Sandstone of the lower parts of the Eden Valley is still above sea-level.

Whatever be the date of the uplift, and the exact manner in which it was caused, the geological structure of the district fully proves the existence of one main dome-shaped uplift and of at least one subsidiary uplift, namely, that lying south-east of the main dome. That these uplifts have determined the present main

drainage of the district seems to have been fully established by Hopkins, and has been generally admitted by subsequent writers. We may now pass to the consideration of the characters of this drainage.

III. Initiation of the Drainage-Lines.

The absence of any connexion between the axis of uplift of the Lower Palæozoic rocks, and the coincidence, on the contrary, of the principal watershed of the district with the line which would mark the summit of the dome (if the Carboniferous and newer rocks, where they have now been removed by denudation, were restored in the positions which they must have occupied according to their existing dips), are so generally recognized that it is unnecessary to do more than indicate the general trend of the valleys from this line. The departure from radial symmetry was recognized by Wordsworth and emphasized by Hopkins. The latter author, however, assigns to the uplift certain valleys which I believe to have been wholly or in part due to subsequent denudation along tear-faults; and I may, in the first place, call attention to the courses which were, I believe, taken by those valleys that were directly due to the elevation of the dome.

Seven important valleys rise within 2 or 3 miles of Scawfell, and radiate thence. These are, beginning at the south-east:—(i) The great Langdale-Windermere valley, which at first runs nearly south-east and afterwards almost due south; (ii) west of this the Duddon valley, running a little west of south; (iii) Eskdale, running south-west; (iv) Wastdale, almost parallel with the last-named; (v) Ennerdale, extending nearly east and west; (vi) the Buttermere-Crummock valley, running almost north-west; and (vii) the Derwent valley, the course of which is at first a little east of north and afterwards almost due north. The area occupied by the drainage of these valleys is bounded by a line which is greater than a semicircle. No fracture, so far as I know, can be traced along the whole length of any one of the valleys, though occasionally their courses naturally coincide with some of the numerous fractures which affect the older rocks. Yet even in these cases, as I hope to show, the coincidence is often due to subsequent diversion of parts of the river-courses.

The valleys now to be noticed, and lying east of these, have their heads some distance to the east of Scawfell; but the watershed coincides with a line drawn from Scawfell to Shap Summit, which is

the line of uplift of the dome, as indicated by the geological structure of the margin of the district.

On the north side of this watershed, tracing the valleys from west to east, we have the Thirlmere valley, which, though now largely along a shatter-belt, probably runs in the general direction of a valley due to a superimposed stream; the Ullswater valley; and those of Haweswater and Swindale. While, south of the shedding-line, again proceeding from west to east, we note first a valley which started near the head of Troutbeck and, as will be maintained later, joined Kentmere at Staveley; Long Sleddale; and Borrowdale (not the well-known valley of that name, but one the stream of which joins the Lune at Low Borrow Bridge).

Taking next the supposed subsidiary uplift of the Skiddaw tract, we again meet with a radial drainage on a smaller scale. Such drainage must, of course, be developed on any mountain of circum-denudation, but in this case the evidence seems to me in favour of subsidiary uplift. The principal streams start from Skiddaw Forest. To the north-west runs Dash Beck, to the south the Glenderaterra (now largely coincident with a shatter-belt), to the east the upper waters of the Caldew, and to the north a tributary of that river.

More complex is the drainage of the tract of land comprising the Howgill and Kirkby-Lonsdale Fells and those fells on the east which are now composed of Carboniferous rocks.

A series of valleys radiate from a point above Widdale Fell, near Hawes. To the north run the headwaters of the Eden, to the west those of Garsdale and Dentdale, to the south the upper waters of the Ribble, to the south-east Langstrathdale, and to the east Wensleydale.

The fact that Silurian rocks are exposed at the surface (save in the inliers along the Craven Fault) to form the fells of the western portion only of this tract is naturally accounted for, on the supposition that the Dent Fault, which threw the Carboniferous rocks down to the east, was of New-Red-Sandstone age; and that, after the faulting, denudation took place and the levelled tract was subsequently covered by newer (Jurassic and Cretaceous ?) rocks, on which the drainage was initiated.

But there is one feature that requires notice. The Lune, from Tebay to Kirkby Lonsdale, runs in a gorge through the centre of that part of the uplifted tract which is occupied by Lower Palæozoic rocks. Geographically, this river rises at Shap Summit. It is true

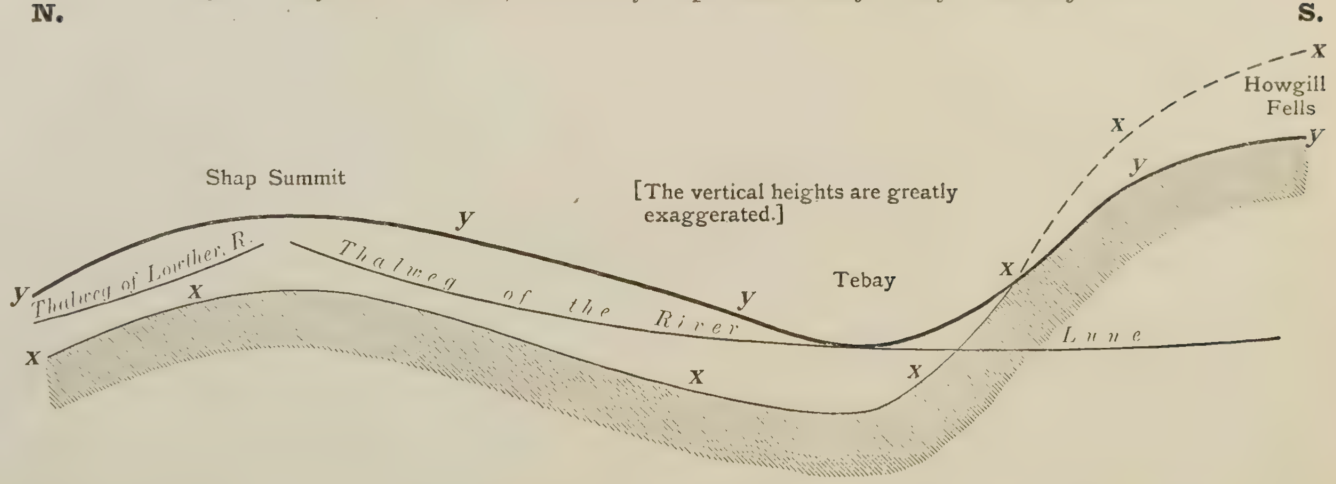
that the most remote source lies far east of this, but the feeder which comes from the east runs in a synclinal fold, whereas the waters which run into the Birkbeck at Shap Wells rise on the axis of an anticline. Here they run at first over Carboniferous rocks, and not until the Birkbeck approaches Tebay does it enter the Silurian tract, in which, as already stated, it continues to near Kirkby Lonsdale.

The geographical source of the Lune is at a height below 1000 feet, whereas the tract of Howgill Fells through which passes the gorge of the Lune (which is a continuation of the Birkbeck valley), has a much greater elevation. A little south of Tebay we have a fell in Grayrigg Forest rising to a height of 1619 feet above sea-level, at a distance somewhat more than a mile west of the Lune, and Uldale Head having a height of 1553 feet about the same distance east of the river. Anyone standing on Shap Summit will be at once impressed by the great mass of Silurian fells on the south, with the general level far above that at which he is located, and will note the sudden change from the wide valley above Tebay to the gorge south of that place. The relationship of the river to the general slopes and to the strata is illustrated in the accompanying section (fig. 5, p. xcviii).

The Shap-Summit anticline is the eastern portion of the spoon-shaped Lake-District uplift; and the Birkbeck stream, therefore, is one of the streams belonging to the radial drainage. At the time of its initiation the mass of the Howgill Fells cannot have stood in the way, unless we suppose that the newer rocks on which the drainage was initiated varied so greatly in thickness between Shap Summit and the top of the Howgill Fells as to allow of a continuous downward slope, over which the river could flow—an extremely unlikely supposition, considering the short distance (less than 10 miles) which separates them. The more likely explanation is that the upper waters of the Lune were first initiated, and that subsequently the uplift of the Howgill and adjoining tracts took place with sufficient slowness to permit of the river (an antecedent stream) keeping its course open, thus modifying the drainage of the western end of the subsidiary dome. I have made this suggestion elsewhere, but it has been adversely criticized, and as I had not then stated all the facts I set them forth here.

One other modification in this tract must be noticed, namely, the general southward flow of the waters of the Rawthey towards Sedbergh. This river, as the result of the lowering of the Lune Valley, probably cut its way back, along the line of weakness

Fig. 5.—*Diagrammatic section from north of Shap Summit through Tebay to the Howgill Fells.*



[The thin continuous lines = streams: that on the north being a tributary of the Eden, that on the south the Lune; the broken line = the continuation of the line of junction of the Carboniferous and Silurian rocks over Howgill Fells; xx = the above-mentioned junction, the Silurian being shaded and the Carboniferous left blank; yy = the banks of the Lowther and Lune valleys.]

produced by the Dent Fault, towards the northern margin of the subsidiary dome.

The various streams, the general courses of which have been described, must have flowed into the depressions formed around the uplifts; and we may now notice the arrangement of the rivers in these depressions. The rivers, along those portions of their courses, will naturally occupy synclinal valleys.

Treating the uplift as a whole, we have, as already noted, two depressions on the east side, the northern one being occupied by those portions of Edenside which lie on the New-Red-Sandstone rocks, the southernmost (which is shorter, owing to the asymmetrical arrangement of the south-eastern dome) carrying the lower waters of the Lune about Lancaster to the portion which is now drowned, forming Morecambe Bay.

The synclinal rivers which must have existed west of the district, if the uplift was sufficient (as was probably the case) to cause the low-lying tracts surrounding the uplift to become land, are also drowned, lying beneath the waters of the Irish Sea.

The lines of junction of the main and subsidiary uplifts would also be occupied by synclinal valleys. The westerly course of the Glenderamackin valley north of Saddleback, and the northerly course of the Derwent, into which it flows by Bassenthwaite Lake, would be accounted for by the subsidiary uplift of the Skiddaw tract.

Again, in the case of the Howgill uplift, we find the stream which flows westward from Ravenstonedale to Tebay and joins the Birkbeck at that place, in a syncline between the Lake-District and Howgill uplifts; and the lower waters of the Kent, from Kendal to its estuary, also occupy a syncline between these two uplifts.

At the time when this drainage was initiated, the whole area was, according to my view, occupied by rocks of Mesozoic or perhaps Tertiary age, and the rivers at first coursed over these rocks. Many tributaries would, no doubt, be developed before these rocks were denuded; and also primary dip-streams, which rose, not at the centre of the dome, but some way down its slopes, as, for instance, the Mite, and probably the river occupying the Coniston valley. It remains to discuss the changes which took place after the covering of newer rocks was removed by denudation, and after the drainage had worked its way down to the Lower Palæozoic rocks. In

discussing these changes it will be convenient to confine our attention chiefly to the drainage of the main uplift, although it will be necessary to make incidental reference to the subsidiary uplifts; and, in the first place, we may briefly consider the effects of the three types of Lower Palæozoic rocks in modifying the surface-features.

IV. Effects of the Three Types of Rock upon the Scenery.

The differences between the hills of the Skiddaw-Slate, Volcanic, and Upper Slate rocks are so well known that little need be said concerning them. The smooth outlines of the Skiddaw-Slate hills, often rising into peaks, form a marked contrast with the craggy and irregular hills of the volcanic tract; these again differ widely from the lower and smoother elevations of the Upper Slates, which are in some degree comparable with those of the Skiddaw Slates.

But, although the general differences are widely recognized, there are some points which require closer consideration.

It is sometimes stated that the volcanic group of hills owe their height to their superior hardness. This is not the case. The highest hill composed of volcanic rocks is Scawfell Pike (3210 feet); while Helvellyn rises to 3118 feet, and some others nearly touch 3000 feet. The highest hill in the Skiddaw-Slate tract is Skiddaw itself (3054 feet); Blencathara or Saddleback (2847 feet) and Grasmoor (2791 feet) come next. Within the circumference of the Lake-District dome the highest point in the Upper Slates is 1819 feet, in the watershed between Long Sleddale and Borrowdale; but, on the Howgill Fells, the Calf attains a height of 2220 feet—1000 feet lower than Scawfell, it is true, but still a considerable eminence.

The slight difference (156 feet) between Scawfell Pike and Skiddaw, hills composed of rocks so markedly different in character and hardness, requires some consideration. Height of land depends upon three factors—the amount of uplift, the antiquity of the uplift, and the resistance of the rocks to the particular agents of denudation which operate upon them.

If the uplift be slight, no matter how hard the rocks, the country will be low. Witness the tracts of Anglesey, for instance, composed of hard rock, but never rising to any great height.

Again, when the antiquity of a land-tract is considerable, however great the original uplift, and whatever be the resistance of the rocks, the district must be worn down, as, for example, has happened in great tracts of Canada.

If the uplift be considerable and recent, the elevations may be relatively great, even when the rocks are not very resistant; thus the fairly-soft Carboniferous rocks of the Pennine Chain rise to a height of 2930 feet on Cross Fell, less than 300 feet lower than Scawfell; while the heights of the English Jurassic rocks nearly touch 1500 feet, and those of the Cretaceous rocks in several places approach 1000 feet.

It is in the middle age of an uplift, when denudation has produced its most marked contrasts between uplands and lowlands, that the effects of the relative resistance of rocks are most marked.

These facts are, of course, well known. I merely refer to them because they are too often overlooked, in the case of the elevations of our own island.

The slight difference between the heights of Scawfell and Skiddaw, and especially the slight change in the elevations of many of the slopes where they pass from volcanic rocks on to Skiddaw Slates on the one hand, or on to the Upper Slates on the other, seems to me to be an additional argument in favour of the youth of the district, speaking in a geological sense.

Again, the general elevation of the tract of Upper Slates of the Howgill and Kirkby-Lonsdale Fells, when contrasted with the comparatively-low ground occupied by these slates in the southern part of the Lake District proper, is explicable on the view that a subsidiary uplift has taken place in the Howgill Fells. The low ground occupied by the Upper Slates of the southern part of the district receives its explanation in the fact that they lie almost entirely at some distance from the axis of the uplift of the dome; when they approach that axis, namely at the head of the southern Borrowdale, we find the fells formed by these rocks reaching their greatest height in the area of the main dome.

The softness of the Skiddaw Slates has produced its effect, not in the general lowering of the watersheds as compared with those of the volcanic tract, but in the more rapid erosive work of the tributary streams coursing down the valley-sides and cutting away the plateaux, thus originating the sharp peaks of the Skiddaw area, and the scarcity of plateaux as compared with the volcanic tract.

It is the greater uniformity of the rocks of the Skiddaw tract than of those of the volcanic district which causes the most marked contrasts. The harder lavas, coarse breccias, and flinty ashes of the latter tend to stand out as cliffs, while the more vesicular lavas and softer ashes are worn away. The flinty ashes of the

Scawfell region, usually inclined at a low angle, often produce scars recalling those of the Carboniferous tracts of the adjacent regions (save in one respect to be noted eventually), and similar scars are often formed by the low-dipping lavas, as, for instance, those of the hills south of Keswick, between Derwentwater and the Helvellyn range, and those of the Eycott Group of lavas on the northern margin of the district. But these scars are rare. Even the harder rocks over the major part of the district usually occur in eye-like masses rapidly dying out when traced laterally. I believe that this is due to the constant occurrence of crushing along lag-faults and tear-faults, and that the rocks where this structure occurs are in truth affected by augen-structure on a large scale. In no other way does it seem possible to account for the comparative scarcity of terraced lines of cliff where the dip is low, and although the rocks of the portions between the 'eyes' are usually masked by vegetation, such evidence as I have been able to collect is in favour of the view just expressed.

The greater shatter-belts, as already stated, affect the three groups of rocks, although they are more easily studied among those of the Volcanic Group than in the Skiddaw Slates and Upper Slates. As, however, they are not confined to the Volcanic Group, we may leave their consideration to the next section.

The general uniformity of the ground occupied by the Upper Slates, recalling that of the Skiddaw Slates, has already been noticed. It is true that the Coniston Grits often stand out to a greater extent than the other rocks, while the Bannisdale Slates, consisting of thin gritty flags, frequently give rise to rocky ground; but these are matters of detail.

V. Modification of the Old Drainage-Lines along Shatter-Belts.

The nature of the shatter-belts has already been discussed: it remains to consider the influence which they have exerted upon the present structure of the region, and as this influence is most readily detected in the area occupied by volcanic rocks, we shall consider chiefly the features displayed in that area.

Among the features most obvious to the casual observer are the deep gashes, or 'rakes,' which often seam the mountain-sides, in the form of straight deep gullies, usually dry, save in seasons of flood. Many of these have been shown by Clifton Ward to occur along dykes, but a very large number are found on inspection to

be cut along the minor shatter-belts. Weathering must take place along these belts to a far greater extent than over the ground occupied by the more resistant rock which bounds them, and the mass of weathered rock would tend to become waterlogged in wet seasons, so that during those occasional periods of heavy local rainfall, locally known as 'cloud-bursts,' the weathered material would tend to be cleared away and a rake initiated. This was probably the origin of the well-known gullies on Blease Fell near Tebay (in the rocks of the Upper Slates) which were formed in the course of a few hours, about the year 1858:

'The rain excavated deep channels in the weathered rock of the hillside, and spread the rubbish over some pasture-land below.[1]

I have elsewhere described a similar gully which has partly destroyed the old Roman Road on High Street. These gullies frequently possess tributaries at the head, arranged like the outspread fingers of a hand, as seen near the foot of Wastwater, and on the slopes of Base Brown above Seathwaite in Borrowdale. Where two such rakes occur on opposite sides of a ridge, that ridge becomes notched, such a notch being shown between the two summits of the Langdale Pikes; and, accordingly, hills composed of nearly horizontally-bedded ashes which ought otherwise to possess fairly-straight ridges are notched, as in the beautiful mountain-screen at the head of Langdale as seen from Windermere.

But it is in those cases where running water is still active, that the influence of these shatter-belts is best appreciated, and to these we may now turn.

In my paper on the 'Waterways of English Lakeland' in vol. viii of the 'Geographical Journal' (1896) I described a gorge in the Langstrath Valley, formed by glacial diversion. It is one of a series occurring above the junction of Greenup Gill with the Langstrath river, and is known as Black-Moss Dub. The main fissures of the shatter-belt are clearly seen in the naked rock at the bottom of the narrow gorge, which is 20 feet deep, the lower 11 feet being occupied by water. At its summit occurs a waterfall, which has obviously cut back along the belt. Here we have a case of erosion to the depth of 20 feet in post-Glacial times. Just below this is another case of diversion, where the water does not flow along a

[1] 'The Geology of the Country around Kendal, Sedbergh, Bowness, & Tebay' Mem. Geol. Surv. 2nd ed. (1888) p. 51.

shatter-belt, but runs down a glaciated rock, in a wide groove only about 3 feet deep. These two cases give us an indication of the importance of shatter-belts in accelerating denudation.

This, however, is not all. The groove in the latter case does not possess a smooth, concave surface, but has angular sides, and the bottom is also angular, with notches cut along the dominant points. Abrasion of the general surface of the rock appears to have little effect, but the water saws along the joints, gradually detaching the blocks, which are then carried away in flood and rounded into pebbles. This is the general character of the rocky waterworn gorges situate in the volcanic region, and not only shows the importance of planes of weakness in determining the amount of denudation in the case of hard rocks, but also accounts for the small amount of mud carried by streams coursing over these rocks as compared with the muddy streams of the Skiddaw-Slate tract. The comparative clearness of flooded streams when running over hard rocks does not, therefore, necessarily indicate that these streams have established their base-lines, but may be due to the different nature of water-erosion acting upon well-jointed hard rocks and on ill-jointed soft rocks respectively. In the action of streams along these joints we have a forcible indication of the work which is done along the shatter-belts which consist of blocks of hard rocks separated by joints, in addition to which there is much easily-eroded crush-material that has been developed along the joint-planes.

We will take one or two other examples of the formation of gorges along shatter-belts.

Of a similar nature to Black-Moss Dub, but on a larger scale, is the gorge at Birks Bridge in the Duddon Valley. Above, as in the case of Black Dub, is an alluvial flat, once occupied by a lake. A dry valley lies to the east, while the Duddon now flows through a deep gorge, headed by a fall. The gorge below the bridge is 23 feet deep, of which 8 feet are under water at ordinary times. The bridge is pierced with holes above the road, for the flood-waters to drain through, these holes being but 3 feet below the top of the rock, so the gorge must be filled to the brim in times of flood. In this case, again, the shatter-belt structure may readily be seen.

The two cases noticed above are on the floors of important valleys, but the greater number of examples of streams occupying

shatter-belts in which the geological structure of the shattered rock is seen, occur on mountain-sides. I may mention as examples Tilberthwaite Gill, in the Coniston Fells, of which the upper part has been excavated owing to glacial diversion; the streams on either side of Wrynose and Hardknott Passes, occupying parts of a great belt the trend of which has been previously noted; the stream behind the cottage at Blea Tarn, Little Langdale; that of Rossett Gill, of Ruddy Gill, of the stream entering Sty-Head Tarn, and of Aaron Slack, occupying parts of another of the great belts; Peers Gill on Lingmell; and those which course down the hill to the east of Watendlath Tarn. Some of these have already been noticed; they are but samples of hundreds scattered through the district.

In the larger valleys, save where glacial diversion has occurred, as above described, it is usually difficult to obtain direct evidence of the existence of shatter-belts, owing to the covering of alluvium which at present exists along considerable portions of their courses. In many cases, however, the shatter-belts which are seen on cols, and down the slopes, if continued along the main valleys, would run along the portions of those valleys that are marked by their straightness, and may often be traced up another hillside at the farther end of such a straight portion. Let us take some instances.

The shatter-belt seen on either side of the col of Dunmail Raise runs in a direction marked by the straight portion of the Thirlmere valley on the north and of the Vale of Grasmere on the south. Each of these valleys when leaving this belt loses this straightness, the Thirlmere valley where the river passes into the Vale of St. John (probably owing to glacial diversion), and the Grasmere Valley where the stream flows from Grasmere to Rydal (perhaps owing to capture of the stream, which once continued along the shatter-belt to Elterwater, by a strike-stream working back along the softer rock of the slate-band between Ambleside and Rydal).

In Great Langdale, the valley below the Dungeon-Gill Hotels is formed by the coalescence of two upland valleys: Oxendale, which is continuous with Crinkle Gill, worked along a shatter-belt on the side of Crinkle Crags, and Mickleden which is worked along one of the three great shatter-belts previously noted. On the line of Mickleden at its upper end this belt is seen in Rossett Gill, and at the lower end it leaves the valley and crosses the col between Great and Little Langdales.

The Oxendale line is continued down Great Langdale as far as the stream which descends from Stickle Tarn, where the valley bends and now runs along a line continuous with that of the shatter-belt seen in the Dungeon-Gill stream. When the stream leaves this line lower down at Chapel Stile, it passes from a wide straight valley to a narrow sinuous one, to join the belt once more in the wide portion of the valley at Elterwater.

In Borrowdale the upper part of the wide and straight Langstrath valley is continuous with a belt running down Allen-Crags Gill at its head; while the other great tributary of Borrowdale near Seathwaite runs in a straight valley, continuous at its head with a shatter-belt occupied by the headwaters of Grainsgill. To these belts we must return later; at present, we may simply note the wide straight features of valleys which can be seen to be continuous with tracts occupied by shatter-belts.

The next cases to be noticed show how parts of one river may be captured by another stream working along a shatter-belt, when the arrangement of the stream favours this.

The first example to which I wish to call attention is the head of Miterdale, between Wastdale and Eskdale. In a paper which was published in the Journal of this Society in 1895 on 'The Tarns of Lakeland,'[1] I maintained that the Mite once rose on Scawfell, and that owing to glacial diversion its upper waters had been switched off into the Esk, with the formation of Burnmoor Tarn. I have been over the ground recently with Prof. Garwood, and we were convinced that I was wrong. If Burnmoor Tarn is a blocked lake, the barrier lies on its eastern bank and not at the south-western end. So far from the upper waters of the Mite having been captured by the Esk, all the evidence is in favour of the possibility of future capture of the upper waters of the Esk by the Mite. The upper part of Miterdale is in a shatter-belt, along which it has cut a gorge terminated upstream by a remarkable combe backed by a cliff, down which several gullies course, the principal stream flowing over the cliff on its western side. This is only about one-third of a mile from Burnmoor Tarn in the Esk drainage, and the col between Esk and Mite is only some 50 feet above the waters of the Esk on the other side of the col. Had the stream which enters the combe from the west been situated nearer Burnmoor, the Esk stream might well have been captured

[1] Vol. li, pp. 42–43.

by that of the Mite; and, even now, some of the minor streams which pour over the combe-cliff from the depression between Mite and Esk may in time accomplish the capture.

It seems clear that this has actually been accomplished at another place, namely Honister Pass, between Borrowdale and Buttermere. In ascending to Honister from Seatoller in Borrowdale, the head of the valley appears to be a combe, down which tributary streams course to join the Borrowdale drainage. On reaching the head of the valley it is seen that the principal of these, flowing from Gray Knotts, passes through a huge gap cleft in the north-western part of the combe, and continues down a valley apparently along a shatter-belt into Buttermere, thus largely determining one of the most prominent features of the district, the huge Crag of Honister.

In the next case the capture is more pronounced. Lingmell Beck flows from the Scawfell group of fells in an easterly direction to the head of Wastwater, along a line of shatter-belts which are occupied by Grainsgill and Spouthead Gill. The valley now passing from Sty-Head Tarn northward to Borrowdale ends abruptly at Sty-Head Pass, where there is a steep descent to Lingmell Beck. Anyone standing at Sty-Head Pass will be convinced that the Sty-Head stream has been beheaded by Lingmell Beck. Apparently at one time the Peers-Gill stream flowed to Wastwater, and the streams which now occupy the Grainsgill and Spouthead gorges into Borrowdale; but the first-named stream, working along the shatter-belt, beheaded the others at an elbow. We shall have occasion to consider this case more fully, when discussing the changes which have occurred in the Borrowdale Valley in greater detail.

From what has been said above, it will be grasped that, according to my view, complications in the original drainage initiated upon rocks which once overlay the Lower Palæozoic rocks, have been produced after the drainage had worked down to the latter owing to the removal of the former, largely because of the tendency for the most strongly-marked erosion to occur along the shatter-belts. I propose to illustrate this further by a detailed consideration of four valleys, namely, Troutbeck near Windermere, Langdale, the Duddon, and Borrowdale.

As I propose to give reasons for believing that the formation of many of the hanging valleys of the district has been largely deter-

mined by the existence of shatter-belts, it will be necessary, before discussing the changes in the drainage in the case of the above-named valleys, to say something concerning the distribution of the hanging valleys. The chief valleys of this nature are situated in the area occupied by the volcanic rocks, in itself a suggestive circumstance, as it is in that area that the contrast between the resistance to erosion of the shatter-belts and the unshattered rock between the belts is most marked.

Some of these valleys, no doubt, owe their character to the fact that they are situate in hard rocks of the Volcanic Series, while the larger valleys into which they ‘mouth’ are in softer rock, either of the Skiddaw-Slate or Upper-Slate Group. Thus the valley in which Coniston Lake is situated is in the Upper-Slate Group, while the hanging valleys on its west, namely those of Goats Water, Low Water, Lever's Water, and that south-east of Wetherlam (of which the water flows through Tilberthwaite Gill), are in the volcanic rocks. Again, the Watendlath valley is in volcanic rocks, and the water flows over Lowdore on to the Skiddaw Slates. The hanging valleys south-west and south of Buttermere are also in volcanic rocks, while the main valley is in Skiddaw Slates. The most remarkable of the hanging valleys of the Buttermere series is that at the extreme head of the valley; this differs from the others in not being a lateral valley, but the upper part of the main valley which ‘mouths’ at a height of about 900 feet above Warnscale Bottom, the alluvial tract above Buttermere Lake.

But the greater number of the hanging valleys are situated in the heart of the volcanic ground, and in all cases appear to be connected with shatter-belts traversing that part of the main valley into which they ‘mouth.’

In addition to those of the valleys which I wish more particularly to describe, I may notice the series on the west side of Helvellyn mouthing into the Thirlmere valley, and those on the east side of the same mountain mouthing into Grizedale, which is certainly along a line of fault. Farther east are the hanging valleys of Small Water, Blea Water, and Measand Beck mouthing into the Haweswater Valley, which lies in a line of disturbance apparently running through the Gatescarth Pass, and those at the head of Swindale, where the main valley seems to occupy a shatter-belt running over the fell to Mardale. Others occur on the side of the Grasmere Valley.

We may now pass to the consideration of those valleys which it is my desire to discuss in greater detail.

The first to which I would call attention is the Troutbeck Valley, occupied by a stream flowing into Windermere from the north. I have already referred to the evidence which this valley yielded, as first giving me an idea of the importance of shatter-belts. Near the head of this valley, on its west side, is the hanging valley of Woundale, which is occupied by a stream rising on St. Raven's Edge and running for about $1\frac{1}{2}$ miles, chiefly on flat ground, ere it mouths at a height of over 1000 feet above the sea, near the Kirkstone-Pass road. Here it falls rapidly to join the Troutbeck stream, some 400 feet below.

About 3 miles lower down the Troutbeck Valley on the east side is a marked notch, forming the head of a valley, which is lower down occupied by a stream eventually flowing into the Kent. On ascending this valley, we find that it has a gently-sloping floor which ends abruptly on the side of the Troutbeck Valley, east of the Church, at a height of about 850 feet above sea-level. This valley is in direct line with that of Woundale.

The appearances are explicable, on the supposition that, before the Troutbeck Valley existed, a stream rose at the head of Woundale, which is on the main watershed of the district, and flowed in the direction which we should expect, namely, somewhat east of south, until it joined the Kent; and that subsequently the Troutbeck stream worked back along the shatter-belt, beheading the Woundale stream, leaving the upper part of the latter as a hanging valley (for no shatter-belt extended up this valley), while the lower part ended in the marked notch at the side of the Troutbeck Valley, and its downward continuation is now marked by a small stream, which seems insignificant when compared with the valley which it occupies.

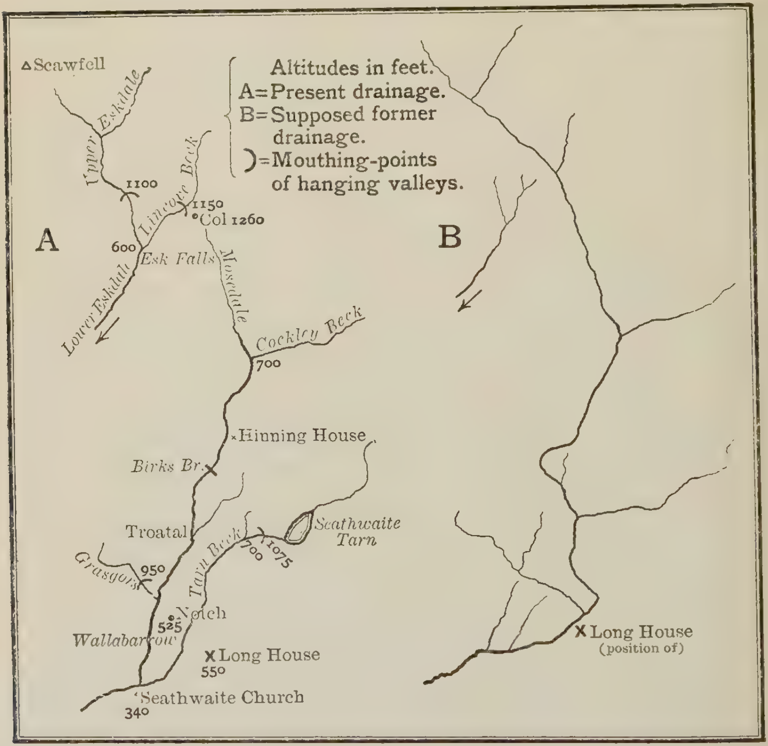
Let us now turn to the Great Langdale Valley, to which I have already alluded briefly.

It was pointed out that a shatter-belt runs up Mickleden at the head of the valley, and passes up Rossett Gill towards the west-north-west. At the foot of Rossett Gill, a stream comes from the north, by the path from the Stake Pass. This stream courses down a steep slope, and, on ascending the path, a marked hanging valley is found, known as Langdale Combe. Passing down the main valley we find its course, as before stated, bearing to the east along

a line continuous with that of the Oxendale shatter-belt; and north of the main valley along this part of its course is the hanging valley containing Stickle Tarn on the Langdale Pikes, which mouths at a height of about 1200 feet above the Great Langdale Beck. Still lower down the main valley, the Little Langdale stream enters from the south-west. It forms another hanging valley, which mouths above Colwith Force.

We may now pass on to consider the Duddon Valley, with which is associated that of the Upper Esk. To illustrate the changes

Fig. 6.—*Map of the upper Duddon Valley and part of Eskdale, on the scale of 2 miles to the inch.*



[*For* 'Lincove' *read* 'Lingcove'; *and for* 'Troatal' *read* 'Troutal.']

which appear to have taken place here, two diagrams are given, of which the second (B) indicates the original drainage as inferred from the structure of the ground, while the first (A) shows the present drainage. (See fig. 6, above.)

I went over the ground with Prof. Garwood last year, and am much indebted to him for help in my investigations.

Beginning with what we believe to have been the former head of the Duddon Valley, now the headwaters of the Esk, we find these headwaters running in an upper valley known as Upper Eskdale. This is sharply separated from Lower Eskdale by a steep slope at the head of the latter, down which course two streams, the Esk itself from Scawfell and Esk Hause, and Lingcove Beck from Bowfell. The latter is separated from the dreary Mosedale Valley at the head of Duddon by a col, at a height of about 1260 feet; and Mosedale is in a line which is practically continuous with that of the Esk stream from Scawfell. There is good evidence on the ground that this old head of Duddon has been tapped by the streams of the Esk and Lingcove Beck, which unite at Esk-Falls Bridge. The details of the change are somewhat complicated, and it is unnecessary to discuss them here. The evidence points to the tapping of the old head of Duddon, firstly by Lingcove Beck, and secondly by the Esk itself. The old valley which runs nearly due east here is wide, while Lingcove Beck and the Esk now escape from it by narrow gorges. The Esk gorge, where the old valley at present mouths, is clearly post-Glacial at the head. It has, at the top, cut through moraine, which now slides down into the rocky gorge beneath. This valley mouths at an altitude of 1100 feet, and that of Lingcove Beck at about 1150, a little more than 100 feet below the present col separating it from the Duddon.

The head of the Lower Esk is a wide straight valley, apparently cut along a shatter-belt, in which the river rapidly deepened its valley. Owing to this, the two tributaries at its head were able to extend their sources backward, thus tapping the old Duddon. If this be so, these two hanging valleys exist as such, because they once formed part of a different drainage; and the time since diversion has been too short to allow of the deepening, to any great extent, of the streams which effected the captures.

Entering now into the region of the present Vale of Duddon, Mosedale Beck after a course of $1\frac{1}{2}$ miles reaches Cockley Bridge, where it crosses one of the great shatter-belts formerly described. Here the valley widens and runs in an alluvial flat to Birks Bridge, where it enters a gorge marked by a shatter-belt which points towards Cockley Beck. At this point there is some indication that the old valley once swung in meanders, first westward under Harter Fell and next eastward over the present ridge into the present

valley of Tarn Beck. In connexion with the old drainage, we may notice a curious dry valley between Hinning House and Troutal, at a considerable height above the present stream. Seathwaite Tarn lies in one of the most important of the hanging valleys of Lakeland, which, beginning at the top of the Carrs (one of the Coniston Fells), runs in a sinuous course for a distance of 2 miles, measured in a straight line, before it mouths at a height of 1075 feet above sea-level and 375 feet above the wide Tarn-Beck valley at the bottom of the slope. This valley is occupied by alluvium at its base, until it reaches the Wallabarrow ridge to be noticed anon. Below the entrance into this valley of the stream forming Seathwaite Tarn there is evidence of another meander marked by a ridge of apparently-waterworn rock at Long House, at a height of 100 feet above the present river on the west, and a wide dry valley extending from this ridge to Seathwaite Church. The height of the Long-House ridge is 550 feet above sea-level.

We now come to one of the most interesting features of the valley. The rocky ridge of Long House is the eastern part of a great rocky spur which rises, on the whole, westward. Below it the Duddon is a wide valley largely occupied by alluvium, although there are evidences of other ancient meanders now cut through along shatter-belts. Looking at this ridge, part of which is known as Wallabarrow, from down vale, it appears completely to block the valley; but two deep gorges cut through it, one occupied by the present Duddon, the other by Tarn Beck.

Above Wallabarrow Gorge, a stream enters the Duddon from the west, flowing past a farm called Grasgors, below which it mouths at 950 feet, and on the other side of the Duddon is a deep notch in the ridge separating the Duddon from the Tarn-Beck valley, the height of this notch being 525 feet above the sea.

Anyone looking up the valley from below, or looking down upon it from Walney Scar on the Coniston Fells, would be convinced that the main river ran over the Long-House ridge, which is now dry.

The changes which seem to have occurred are as follows:—In former times when the Duddon below Birks Bridge ran into the Tarn-Beck valley and over the Long-House col, the Grasgors stream would run through the notch east of the present Duddon, to unite with the old river above Long House, while a tributary of Grasgors would no doubt flow from the north. The first change was the formation of a gorge through the Wallabarrow

ridge above Seathwaite Church, along a small stream flowing down the ridge in a shatter-belt. When this stream tapped the river to the north, the Long-House ridge would be turned into a wind-gap, and the valley above the new gorge deepened, as also that of the Grasgors tributary flowing through the notch, the summit of which is now 25 feet below the Long-House ridge. Owing to the deepening of the Tarn-Beck valley, the Seathwaite-Tarn valley became converted into a hanging valley.

In the meantime, a stream to the west of the Seathwaite stream, occupying another shatter-belt, sawed through Wallabarrow to form the present gorge of the Duddon, and thus caused the deepening of the tributary of the Grasgors stream, converting the Grasgors stream itself into a hanging valley. Finally, this tributary extending backward captured the waters of the Upper Duddon from the Tarn-Beck valley, below Birks Bridge, giving rise to the present drainage.

It may be noted that the bottom of the Seathwaite gorge through the Wallabarrow ridge is well-glaciated, showing that the diversion from Long House occurred before the last occupation of the district by ice, and my impression is that the whole of these diversions were produced in pre-Glacial times, although it is extremely difficult to prove that none of the changes were caused during an early glaciation.

The phenomena of the Duddon valley, then, go to show that an ancient river belonging to the radial drainage impressed upon the dome established its base-level, and had a meandering course from Scawfell to a point not far from its estuary. After this there was uplift and renewed activity, but the meandering stream, cutting on the whole across the shatter-belts, was only deepened along its original course where that happened to coincide with a shatter-belt for some distance, as below Cockley Beck. Owing, however, to the less resistance of the rocks along these shatter-belts, considerable modifications of the drainage ensued, with the production of the hanging valleys of the Upper Esk, and of Seathwaite Tarn and Grasgors.

The last valley that I propose to consider in detail is perhaps the most interesting and the best known, namely Borrowdale.

As in the case of the Duddon, it will render the description clearer if two diagrams are examined side by side, the one showing the present drainage, and the other that which I believe to have

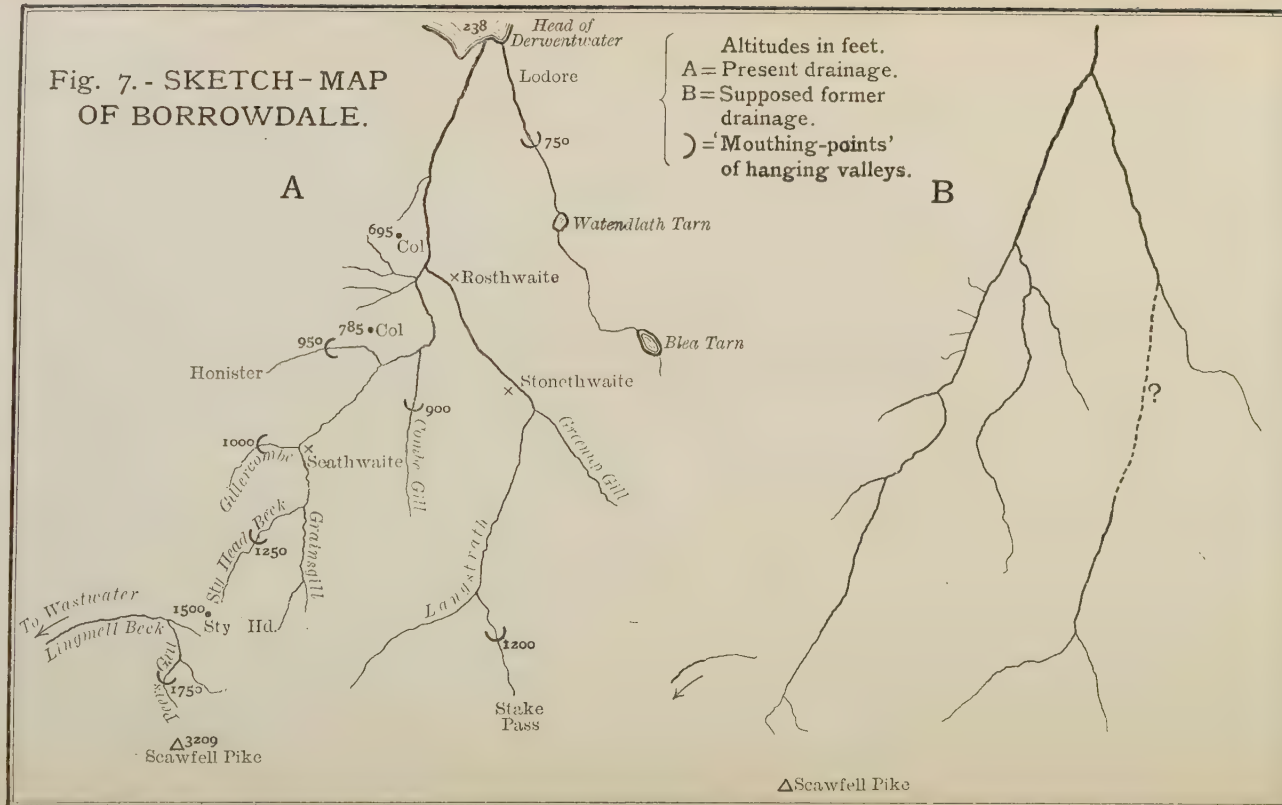


Fig. 7.- SKETCH-MAP OF BORROWDALE.

[Scale: 1 inch = 2 miles.]

originally existed as the result of the elevation of the dome. (See fig. 7, p. cxiv.)

At the present day the Borrowdale valley is occupied by a stream formed by the coalescence of two feeders, the Seathwaite Beck[1] from the south-west and the Stonethwaite Beck from the south-east, which unite below Rosthwaite, and the River Derwent formed by their union flows northward to Derwentwater. The true head of the Derwent is on the Scawfell group of fells, and the valley is one of the original radial valleys due to the elevation of the dome. The Derwent passes from the volcanic rocks on to the Skiddaw Slates, near the village of Grange. Its erosive power over the tract occupied by the volcanic rocks was no doubt due, as in the case of so many other valleys, to the more rapid denudation of the Skiddaw Slates in earlier times, producing a fall-line at the junction of the two sets of rocks. Above this junction at the present day the courses of the Derwent and its two principal feeders coincide with the trend of three important shatter-belts. The lowest of these runs in a general southerly direction from Grange through the Jaws of Borrowdale, past Rosthwaite and Stonethwaite Beck, above Stonethwaite in the direction of the Greenup valley. Its existence is indicated by the geological structure, for on its east side for a long distance is the Falcon-Crag Group of volcanic rocks, and on its west side the Ullswater Group. At Galleny Force, about 1 mile south-east of Stonethwaite, another shatter-belt, the existence of which has already been considered, passes up the Langstrath Beck to its head.

At Stonethwaite Church another belt passes up the Seathwaite feeder as far as Seathwaite hamlet, its presence being also indicated by the geological structure, among other things by the disappearance of the igneous rocks around the graphite-mine on the west side of Seathwaite Valley. South of this the belt turns due south (where another belt runs obliquely across the valley) and is traceable up to and beyond the head of Grainsgill.

It is in the highest degree improbable that the stream initially produced as the result of the establishment of the radial drainage should have coincided with a shatter-belt, at the point where it crossed from the volcanic rocks to the Skiddaw Slates; and all the modifications which I am about to describe can be accounted for, on the supposition that the waters of this drainage-system found their

[1] This is, of course, a different Seathwaite from that of the Duddon Valley.

way on to the shatter-belt at Grange at a fairly-late period in the history of the rivers.

It is probable that, at a very early period in the history of the drainage, two important streams ran in the general direction of the present Seathwaite and Stonethwaite feeders, uniting lower down (perhaps near the present site of Derwentwater) to form the Derwent, the drainage at this time being, of course, at a much higher level than that of the present streams.

The ancient Stonethwaite stream may indeed have flowed past the site of Dub Tarn into the Watendlath Valley and past Lowdore, for the Stonethwaite Valley is on the same line with that of Watendlath, and there is a depression through Dub Tarn connecting the two valleys. As this depression is over 1300 feet above sea-level, the abandonment of this part of its course by our hypothetical stream must (if it occurred) have been an early event. The Seathwaite stream at this time, as we shall presently argue, did not flow through the Jaws of Borrowdale, which were accordingly then closed, so far as the main drainage was concerned, but were no doubt occupied by some stream the actual course of which was sufficiently close to the shatter-belt to allow of the stream working into it. This stream may well have been that which rises on Glaramara and flows through Combe Gill.

Granting the possibility of this arrangement, the present features connected with the drainage are readily explicable.

The stream from Combe Gill would enter the shatter-belt which extends up the Seathwaite valley east of Seatoller; flowing north-eastward it would join the shatter-belt which now passes Rosthwaite and the Jaws of Borrowdale close to the site of Seathwaite Church, and would flow along this belt through the 'Jaws' on to the Skiddaw Slates. This stream, working back from the fall-line, would cut a gorge through the 'Jaws,' and up the present main valley to Seathwaite Church, and then along the more southerly shatter-belt to the foot of the present Combe Gill.

We will now consider the changes which would occur along the lines of the two great feeders of Stonethwaite and Seathwaite, beginning with the former, the structure of which is comparatively simple.

A tributary stream would enter the stream that has been just described, from above Seathwaite; its valley running along a shatter-belt would be deepened, and receding would capture the

waters of the Langstrath valley, if they previously flowed in the direction of Watendlath. If they did not, they would have flowed in their present direction, and the case is perfectly simple.

When the drainage of the Langstrath was connected with that along the Rosthwaite shatter-belt, the Langstrath valley would also be deepened along its own shatter-belt and establish its present grade. In so doing, it would convert the valley, through which the path over the Stake Pass comes, into the hanging valley which it now is.

It is, however, the Seathwaite branch of Borrowdale that presents points of the greatest interest. I shall give reasons for believing that considerable modifications have occurred along the course of this valley, which produce some very striking scenic features. It will perhaps render the explanation simpler, if at the outset I state what I consider to have been the course of this old stream, as shown in the map (fig. 7, p. cxiv) and section (fig. 8, facing p. cxviii) and then discuss the evidence which points to my conclusion.

I believe that the Seathwaite feeder of Borrowdale originally rose on Scawfell Pike (3209 feet) and flowed generally northward through a valley which has now been cut through by the head of Wastdale. The remnant of this valley mouths at about 1750 feet on the south side of the present Wastdale Valley, and its beheaded part is again struck at the north side of that valley close to Sty-Head Pass (1500 feet). Thence it has undergone little change for about a mile, until it mouths above Taylor-Gill Force at about 1250 feet. It then flowed far above the present valley past Giller-combe above Seathwaite hamlet, which mouths at about 1000 feet, and to Seatoller where the Honister Valley mouths at 950 feet, some way back from the course of the old valley. It then passed between High Doat and Seatoller Fell, where a depression at 785 feet marks its course, and farther north between Castle Crag (west of the Jaws of Borrowdale) and Lobstone Band, where there is another depression at 695 feet, and so over the fall-line on to the Skiddaw Slates, to join the other feeder of the Derwent about the site of Derwentwater.

In the section (fig. 8, facing p. cxviii), which is drawn to true scale, vertical and horizontal, the broken line represents the present line of drainage and the continuous line the supposed ancient line.

The heights of the various points enumerated, which are all those of important and exceptional physical features that require explanation, can hardly occur along the gradually-falling line which is

shown in section, as the result of mere coincidence. Leaving out of consideration for the moment the supposed capture of Wastdale, we have in order, the mouthing of the Sty-Head Tarn Beck above Taylor Gill, that of Gillercombe and that of the Honister Valley, and the cols west of High Doat and Castle Crag respectively.

The depressions in which these cols occur certainly suggest parts of an old valley, and especially is that the case with the depression behind Castle Crag, which (when viewed from High Doat) presents a **U**-shaped cross-section like that of a fairly-important river-valley.

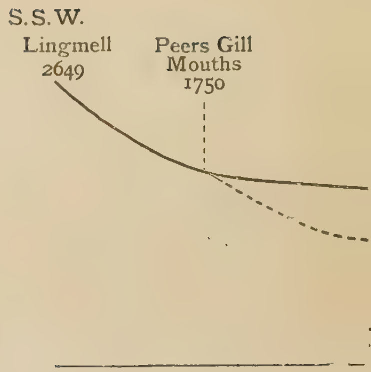
Granting the deepening of the present Borrowdale valley between the mouth of Combe Gill and the Jaws of Borrowdale (which must have taken place, though not necessarily in the way discussed above), the explanation of these features is simple. Beginning downstream we first notice that the main Borrowdale stream has shifted westward, west of Rosthwaite, where a great sweep of alluvium runs, to the concave fell-side, where Tongue Gill comes down. This westerly shifting of the stream would gradually cut away the ridge between Borrowdale and the upland valley, diverting its waters into Borrowdale, and leaving the part of the upland valley on the north as the depression west of Castle Crag.

But the most important change would be the similar action of the Combe-Gill stream on the west at the foot of Honister. The evidence points to the present and old valleys having formed two loops at this point with their convexities approaching one another. If the Combe-Gill stream cut into the upland valley, the upper waters of this would now be diverted into the main Borrowdale valley (this may have happened before or after the capture west of Rosthwaite).

Thus the High-Doat depression would be converted, like that of Castle Crag, into a wind-gap. But the most important result would be that the stream, which formerly flowed from off the Seathwaite shatter-belt to a part of the valley (between Honister and Castle Crag) not occupied by such a belt, would be put in connexion with the Borrowdale stream, which had already deepened its course along its belt; and therefore the Seathwaite stream would now be capable of deepening its valley. This it has done to the head of Grainsgill, leaving Honister, Gillercombe, and the Sty-Head valley as hanging valleys.

We now pass to the consideration of the head of the Sty-Head

To face p. cxviii.]



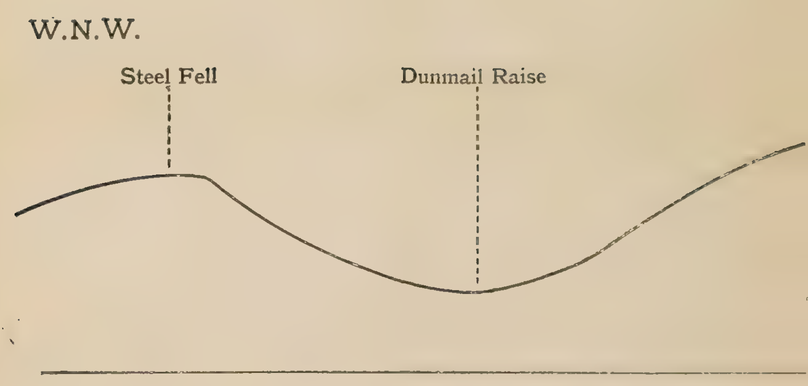
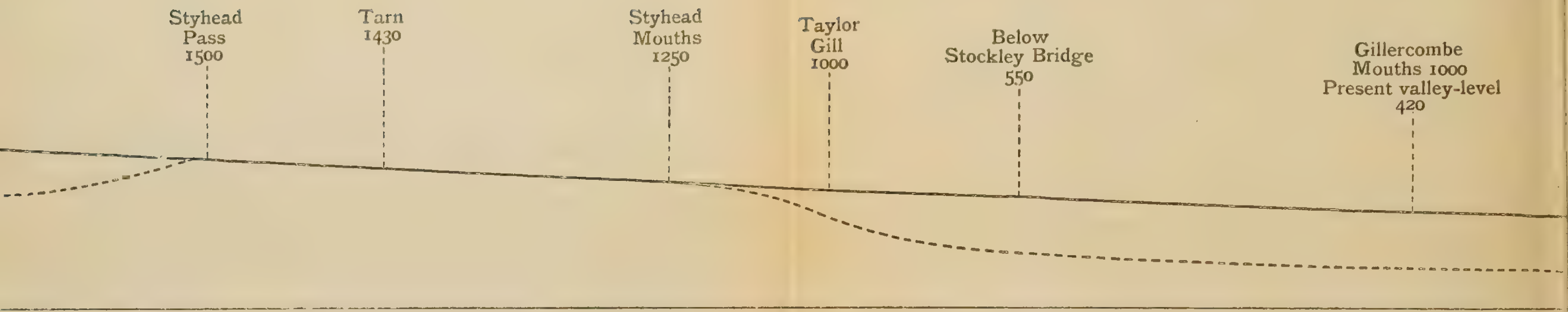


Fig. 8.—*Section along the Seathwaite branch of Borrowdale, continued northwa*

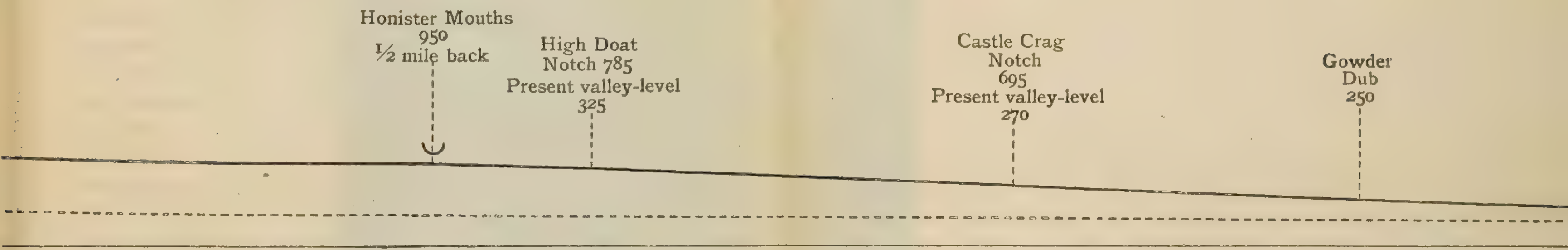


[The continuous line shows the former thalweg, the broken line (when it departs from this)

Fig. 9.—*Section from near Dunmail Raise to Kentmere, to show the convex curves of the*

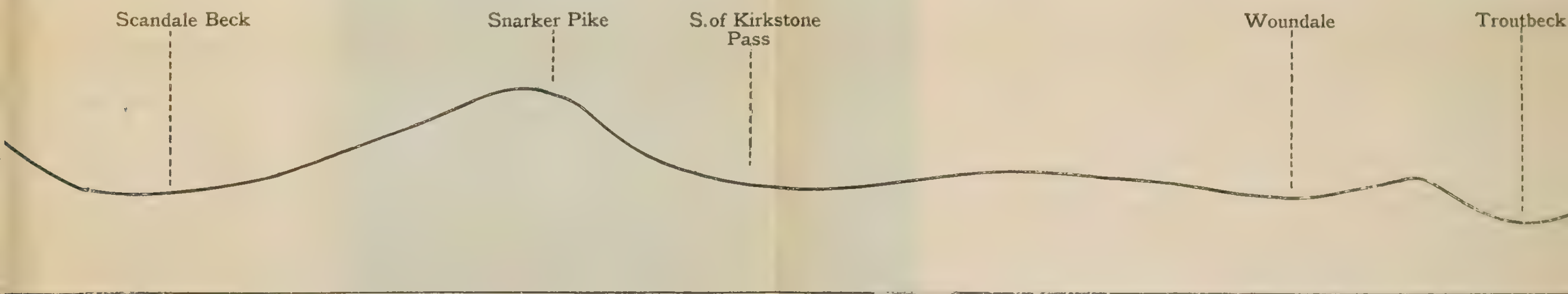
[I am indebted to Mr. R. H. Rastall, M.A., F.G.S., Fellow of Christ's College, Cambridge,

the end of the Honister Valley to the head of Derwentwater. (*Scales, vertical and horizontal: 3 inches = 1 mile.*)



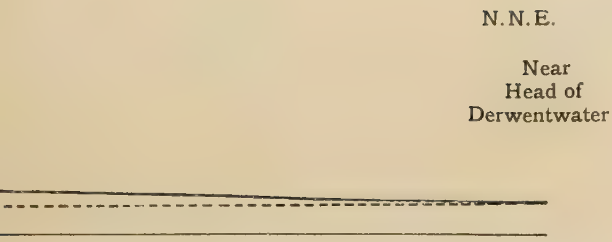
sent thalweg, except between Lingmell and Sty-Head Pass, where the section cuts across the head of the Wastwater valley.]

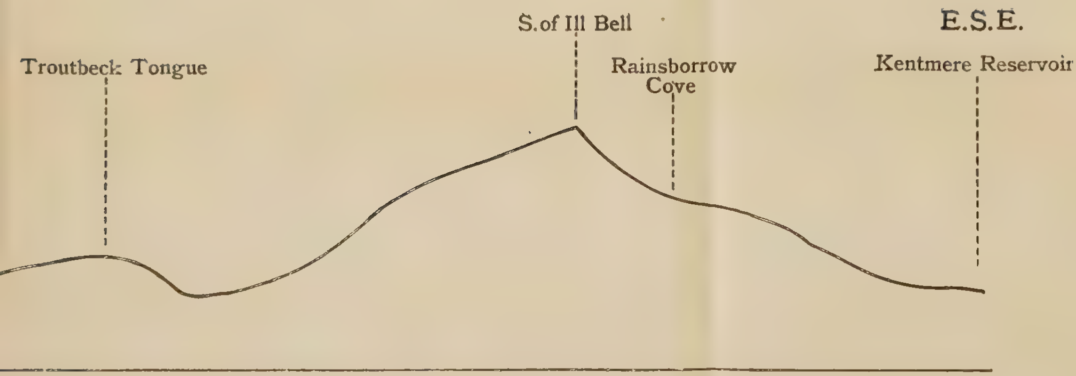
ill-slopes facing westward, and the concave slopes facing eastward. (*Scales, vertical and horizontal: 3 inches = 1 mile.*)



ing out the above sections, as also those across the hanging valleys of Bleaberry Tarn and Gillercombe.—*J. E. M.*]

[Quart. Journ. Geol. Soc. Vol. LXII, May 1906.





valley. Proceeding southward from Sty-Head Tarn one ascends gradually up the gently-sloping valley-floor, until on reaching the watershed the ground falls steeply away to Lingmell Beck, which flows into Wastwater. The bottom of the Lingmell valley is there about 350 feet below the Sty-Head col.

Lingmell Beck itself runs along an important shatter-belt. On the other side of this belt are Peers Gill and Greta Gill, with deep gorges which cut into old hanging valleys. The former may have been always connected with the Wastwater drainage and the latter at one time with the Sty-Head drainage, although the physical features suggest that each drained into Sty Head, and that when the capture took place, the streams working along minor shatter-belts were able to incise deep gorges in and below the old hanging valleys. The Peers-Gill stream, with its **Z**-shaped course through a valley which seems to have been originally straight, forms an excellent illustration on a small scale of the manner in which the course of a stream may become modified owing to shatter-belts.

Another feature seems to be also due, or partly due, to the capture of the upper waters of the Sty-Head valley. The stream that descends between the two Gables has brought down a vast quantity of flood-material, which the diminished main stream has been unable to carry away; and accordingly its dry delta now passes across the main valley at the foot of Sty-Head Tarn, either entirely forming the tarn or increasing its depth and size.

Having described in detail the various features connected with shatter-belts and their influence upon hanging valleys, it will be well to make a few general remarks about the latter, so far as the Lake District is concerned.

A large number of the hanging valleys of the district have been shown to occur where there is strong evidence of the existence of shatter-belts along the main valley, and not down the hanging valley; and in many other cases the structure of the main valley suggests a shatter-belt where the direct evidence is not so striking.

These valleys are marked by the straightness of their courses and absence of meanders. Where the shatter-belt has been directly responsible for the formation of a valley, as in the Windermere Troutbeck, the whole valley possesses a straight course.

When valleys were initiated on the dome, not at first under the influence of shatter-belts, they had established meanders, which became incised, as in the cases of Upper Langdale, the Duddon

Valley, Ullswater, and others. Where these valleys have subsequently been modified by erosion along shatter-belts the modified parts are marked by their straightness, as, for instance, that part of the Duddon which lies between Wallabarrow and Birks Bridge.

In some cases the lower parts of valleys which in higher parts run along shatter-belts are marked by crooked courses, as in the case of the Duddon and Grasmere valleys. In these instances the lower portions are in rather soft rocks, or at any rate in very well-jointed rocks, which were somewhat easily eroded, and where, indeed, the major shatter-belts are often replaced by hosts of minor ones.

I lay special stress on the straightness of the valleys along lines of shatter-belt, as the absence of overlapping spurs in such valleys has been used as an argument for the deepening of these valleys by ice. Whether that deepening be by ice or water, this straightness is not due to the eroding agent, but to the rock-structure.

The width of the valleys and the occurrence of wide alluvial floors at their bases shows that, if eroded by water, they established their base-levels at a remote date; and it may be argued that this being so, the hanging valleys ought to have established their grades. That they will do so some day under present conditions is clear; but if the amount of erosion carried on by these streams, on rocks not occupied by shatter-belts, is insignificant when compared with that of the streams which do run over shatter-belts: then, notwithstanding the time which has elapsed since the main streams established their base-levels, that interval may be but a fraction of the whole time required for the adjustment of the grades of the tributaries.

It must be noted also that they are, by degrees, adjusting their grades. Sty-Head Beck, for instance, has cut a good deal back from Taylor-Gill Fall, and is raising its bed at the bottom of that fall by building up a delta-fan; and the same is the case with the other hanging valleys in varying degrees.

We may note further that, where tributary streams are themselves along shatter-belts, they do not occupy hanging valleys: as witness the various streams which descend into the Rothay above Windermere, from Fairfield and Red Screes.

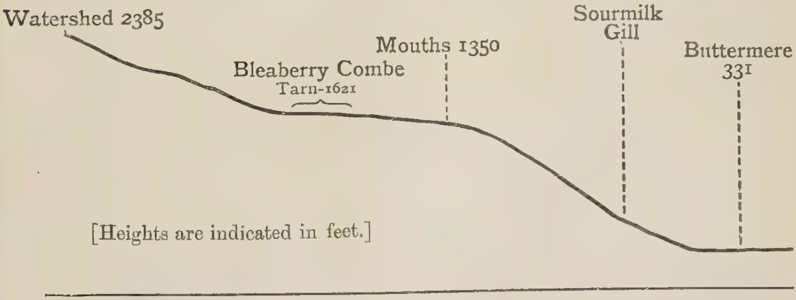
The importance of hanging valleys is apt to be overestimated as the result of casual inspection. Some valleys which appear to

'hang' are drained by streams which have nearly or quite established their base-levels; although, when these streams run at the bottom of narrow gorges, the effect is one of a hanging valley. Others, again, are due to glacial diversion; but these are on a small scale.

A point which may sometimes be important in diminishing the erosive power of the stream of a hanging valley may be noticed. When the grades of the tributaries are adjusted to the main stream, the plane of saturation in the main stream and its tributaries may coincide with the surface of the ground. When a main stream has deepened its valley, causing its tributaries to hang, the plane of saturation of the latter may be lowered, on account of springs breaking out on the side of the main valley below the tributaries, thus diminishing the volume of the latter.

Before leaving this part of the subject I may say a few words regarding the sizes of some of the principal hanging valleys of the district, and the heights at which they 'mouth,' for I believe that many are unaware of the importance of some of these valleys.

Fig. 10.—*The hanging valley of Bleaberry Tarn.* (*See p. cxxii.*)



[Scales, horizontal and vertical: 3 inches = 1 mile.]

The largest is Measand Beck near Haweswater, which has a total length of about 3 miles. Along a portion of this distance its valley-floor is nearly flat, forming Fordingdale Bottom. Seathwaite-Tarn valley above the Duddon we have already noticed, as being 2 miles in length measured along a straight line. Church Beck, on the other side of the Coniston Fells, has a course of nearly 2 miles above the point where it mouths, and Sty-Head Beck occupies $1\frac{1}{4}$ miles from Sty-Head Pass to its 'mouth.' Several others are of about this size.

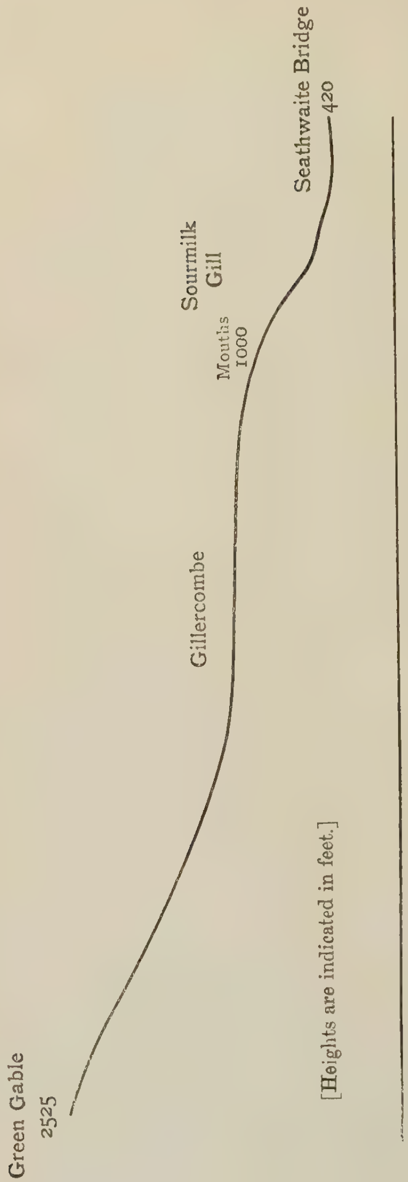


Fig. 11.—*The hanging valley of Gillercombe.* (*Scales, horizontal and vertical: 3 inches = 1 mile.*)

As regards height, the highest pronounced hanging valleys are without doubt that occupied by Bleaberry Tarn, which drains by Sour-Milk Gill[1] to the foot of Buttermere, and mouths at 1350 feet, over 1000 feet above the lake; Warnscale at the head of Buttermere, which mouths 900 feet above Warnscale Bottom; and that of Stickle Tarn, 1200 feet above Great Langdale. It is true that some of those on the west side of Helvellyn 'mouth' at a greater height, but the mouths are not so well defined. Of others, where the transition from the flat hanging valley to the slope below the mouth is very abrupt, we may notice Gillercombe, which mouths about 600 feet above Seathwaite Beck, and the stream at the Head of Swindale, which, mouthing over

[1] The expressive term Sour-Milk Gill is indicative of a hanging valley. There is another from the hanging valley of Easedale Tarn near Grasmere, and a third from Gillercombe at Seathwaite.

500 feet above the main valley, descends at Hobgrumble Gill to join it. Sections along Bleaberry-Tarn valley and Gillercombe are drawn to true scale, vertical and horizontal, in figs. 10 & 11 (pp. cxxi & cxxii).

It will be seen that many of the valleys of the district have been deepened by 500 to 1000 feet since the time when the tributary valleys had grades adjusted to those of the main valleys—a very appreciable proportion (in some cases considerably more than one third) of the entire depths of the valleys.

VI. Depression of the Outskirts of the District.

At the time of the deepening of the main valleys with the production of hanging valleys, the country must have stood much higher than it does at the present day, and was probably connected with the Isle of Man, St. George's Channel being then dry land. The exact height above present level is unknown, but various buried valleys filled with Drift give some indication of the minimum height.

In the Memoirs of the Geological Survey, Explanation of Quarter-Sheet 91 N.W. (the southern part of the Furness District), is a record of a boring at Park House Iron-mine near Dalton-in-Furness, where 537 feet of 'pinel' (Glacial Drift) was pierced before the solid rock was reached, the top of the bore being about 150 feet above sea-level, and rock occurring at the surface at no great distance on either side.

At this time the submergence of the Morecambe-Bay depression and the Solway portion of the Eden-Valley depression must have occurred; and in the former area the old valleys which were, as already stated, formed along wedge-like masses of Carboniferous rocks let down among the Lower Palæozoic rocks, were converted into the estuaries of the Duddon, Leven, Winster, and Kent. These estuaries have since been largely silted up and converted into the peat-mosses which, backed by the Lakeland fells, form so prominent a feature of the southern part of the district.

More oscillations have since occurred, which are indicated by the raised beach near Silverdale, but these are not important as bearing upon the general features of the district. If the uplift of the dome occurred chiefly in Miocene times, and the depression in pre-Glacial times, this would limit the chief period of formation of the valleys of Lakeland to Miocene and Pliocene times.

VII. Effects of Meteorological Conditions.

(1) Hill-Outlines.

In a paper in the 'Geographical Journal'[1] I briefly called attention to the different slopes presented by our hills on the sides facing south, west, or south-west, and north, east, or north-east respectively, pointing out that those facing the former directions often possessed a convex outline on the summit, becoming concave only in the lower parts of the valley, while the slopes in the opposite directions were often concave from valley-bottom to hill-summit, or to a point not far below that summit; and I argued that the convex outline was the result of weathering on peat-covered ground where stream-action was insignificant, while the concave sides marked slopes where the rock was at the surface, and the outline was the ordinary curve of water-erosion. Further observation has convinced me of the frequency of this association, and the few exceptions that occur are readily explicable by the geological structure of the ground.

To illustrate these remarks I would refer to fig. 9, facing p. cxviii, which is a section to true scale drawn across the hills of the High-Street, Kirkstone, and Helvellyn groups of fells from Kentmere to the west side of Dunmail Raise, in a direction approximately from east-south-east to west-north-west. The difference of contour has nothing to do with the strike of the rocks, which cross the valleys nearly at right angles. The valleys chiefly run in shatter-belts, and are, as before described, straight and wide.

The difference in the curvature of the two sides of the valleys is very well marked, as may be readily seen on the ground from a point west of Pull-Wyke Bay at the head of Windermere.

It might be suggested that the difference was due to glaciers having lingered for a longer period on the sides facing north, north-east, or east, than on those facing south, south-west, or west, but there is no sign of this in these valleys. Indeed the absence of anything approaching combes in the greater number of the valley-sides, and the directions of the striæ, indicate that these valleys were not occupied by lateral glaciers, but by ice moving along the direction of the valleys, and there is no reason why this should affect one side differently from the other.

Whether my explanation be correct or no, the appearance is significant, and requires elucidation.

[1] 'The Origin of Moels & their Subsequent Dissection' vol. xvii (1901) pp. 63–69.

(2) The Glacial Period.

I do not propose to treat of the glaciation of the district at length. The writings of Clifton Ward in our own Journal and in the Memoirs of the Geological Survey give an account of nearly all that is known (mainly through his own labours) of the subject, for little has since been done.

We are at present concerned with the influence which the ice exerted in the direction of modification of the drainage-lines. That small diversions have been produced by ice is abundantly clear, the examples already noted in the Langstrath valley being typical cases: but it is doubtful how far diversion has occurred on a large scale, owing to our ignorance of the events which happened during the period of maximum glaciation.

It is in connexion with the larger existing lakes that the evidence seems most clear, as described in my paper on 'The Waterways of Lakeland,' though all the cases therein noticed will not hold good, as, for instance, that which I described in the case of Wastwater along the line of Countess Beck.

The presence of dry valleys at the foot of Bassenthwaite Water, Thirlmere, and Windermere, however, points to diversion; of these, the most striking is that of Windermere, concerning which a few remarks may here be made.

In order to produce diversion, it is not necessary that a lake should be formed entirely by the construction of a glacial dam. If the lake is partly due to erosion or earth-movement, and partly to the formation of a dam, the waters may be switched into another valley. And here I must confess that, in papers which I have written in former years, in discussing the origin of the lakes of this region, I have overestimated the importance of these dams. As the result of subsequent examination on many occasions, I am convinced that Watendlath Tarn and Elterwater among the smaller lakes, and Thirlmere among the larger, lie in true rock-basins. This being so, many of the other lakes may be partly in rock-basins, and owe not their origin, but only an increase in size, to the barriers of Glacial Drift.

Windermere certainly owes its present water-level to such a barrier, which, as I have elsewhere described, blocks the Cartmell Valley at the foot of the lake. This valley is a wide important valley occupied by an insignificant runnel. The water has been diverted into its present course to the west of the old valley, passing Haverthwaite and entering the Leven estuary. It is clear that this stream is

too large for the valley, and has not had time to adjust itself to the new conditions.

Now, in order that the waters of a lake may be switched off from one valley to a parallel one, it must rise up a tributary of the former until it reaches a col over which the waters of the lake will find egress. This has occurred at the foot of Windermere, and accordingly the lake has a hook-like end, the bent portion turning westward near Newby Bridge; and similar hooks occur, although not so well defined, at the lower ends of some of the other lakes.

It would appear, then, that diversion has occurred on a fairly-large scale, as the result of glacial action. Nevertheless, I believe that many of the cases which I have described were produced in pre-Glacial times, especially those in the uplands.

That many of the U-shaped valleys were to some extent widened by ice may be regarded as certain, and this widening may in some cases have been important. I see no evidence, however, that these valleys have been over-deepened by that agent, in some cases to an extent of over 1000 feet; and, for reasons given above, I regard this deepening as essentially the act of water working along shatter-belts.

The changes which have taken place since the Glacial Period do not bear upon my present subject in any high degree. The principal events of that time are recorded by Clifton Ward in the Survey Memoir on 'The Geology of the Northern Part of the English Lake District.'

VIII. Conclusion.

I have endeavoured to show that, so far as the present physical features of the English Lake District are concerned, the events which produced them are, in a geological sense, recent, beginning with the great period of continent-formation in Middle Tertiary times, and that most of the changes to which the district owes its surface-forms occurred in Miocene and Pliocene times, although these forms owe much of their characters to the structures which were impressed upon the rocks at a period far more remote.

I regard the shatter-belts as having played the most important rôle in causing the modification of the lines of drainage which were originally impressed upon the area when the dome was elevated. To the existence of these shatter-belts I attribute that intricate network of upland and lowland which is so marked a feature, particularly in the central portion of the district.

I must admit that there is much that is speculative in this Address, and, so far as details are concerned, I have made suggestions some of which may be proved to be untenable as the result of future work. Many, indeed, of my inferences may appear to be especially doubtful to those who do not know the district; for it is impossible to do justice to the significance of features which appeal to one forcibly when they are actually viewed, without entering into an excess of detail which would extend this Address to an inordinate length. The cumulative evidence that I have collected points, however, in one direction, namely that erosion has occurred so much more rapidly and extensively along the lines of shatter-belts than over the intervening tracts of rock, that these belts are of great significance in determining the amount of erosion.

This is, I believe, not a matter of mere local importance, but will have wide application. We have hitherto acquired our knowledge of the laws of water-erosion by study of comparatively-soft rock, where the work proceeds *pari passu* over all parts of any tract of rock of similar lithological constitution, and the divisional planes are of subsidiary importance. In the case of hard rock, I regard these divisional planes as of primary import, and the texture and hardness of the rocks as playing a minor part. As these divisional planes are so frequently concealed for long distances beneath the superficial accumulations of the valley-floors they are apt to escape detection, and accordingly I believe that their importance has been largely underestimated.

I need not apologize for having confined myself to a particular district, instead of roaming over the world at large in search of illustrations. I have known and loved the district since my boyhood's days, and would fain induce more geologists to visit a region where geology and physical geography can be studied under conditions that stimulate much that is good beside the spirit of scientific enquiry.

In my Address I have tried to answer two questions put forward by Ruskin in 1877 [1]:

'first, what material there was here to carve; and then what sort of chisels, and in what workman's hand, were used to produce this large piece of precious chasing or embossed work, which we call Cumberland and West*e*-moreland.'

My term of office as your President is now over. In offering my

[1] 'Deucalion,' edition of 1891, p. 211.

thanks to the Officers and permanent officials, to the Council, and to the general body of the Fellows, for the invariable kindness that I have received and the assistance rendered to me during the two years in which I have occupied this Chair, I am making no coldly-formal recognition of the benefits extended to me—benefits which have made my term one full of happiness.

You have shown by your selection of my successor, who is now for the second time President, that you are aware that an important event in the history of the Society will mark the period of his occupation of the Chair. I refer to the celebration of the Centenary of our foundation.

We all wish that this celebration may be observed in a fitting manner, and have ensured the fulfilment of our wish by the election of Sir Archibald Geikie to the Presidency.

February 21st, 1906.

Sir ARCHIBALD GEIKIE, D.C.L., Sc.D., Sec.R.S., President, in the Chair.

Herbert Bolton, Curator of the Bristol Museum, 18 Devonshire Road, Westbury Park, Bristol; James Cross, 4 & 6 Church Street, Camberwell, S.E.; and F. W. Hilgendorf, M.A., D.Sc., Agricultural College, Lincoln (New Zealand), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Constitution of the Interior of the Earth, as revealed by Earthquakes.' By Richard Dixon Oldham, F.G.S.

2. 'The Tarannon Series of Tarannon.' By Miss Ethel M. R. Wood, D.Sc. (Communicated by Prof. Charles Lapworth, M.Sc., LL.D., F.R.S., F.G.S.)

The following specimens, etc. were exhibited:—

Fossils from the Tarannon Series, exhibited in illustration of the paper by Miss E. M. R. Wood, D.Sc.

Dental Bone of *Coniosaurus crassidens* (Dixon) from the *Holaster-subglobosus* Chalk, Burham, near Rochester, exhibited by G. E. Dibley, F.G.S.

The following MS. work was exhibited by Henry Johnson, F.G.S.: 'A Specimen of a Natural History of the Earth, particularly with regard to new Islands raised out of the Sea, of whose Origin an Exact Account is given, with a view to establish Dr. Hooke's Theory, concerning the Origin of Mountains & of Petrified Bodies,' translated from the German of Ralph Eric Raspe, 1763.

March 7th, 1906.

Sir ARCHIBALD GEIKIE, D.C.L., Sc.D., Sec.R.S., President, in the Chair.

James Archibald Douglas, B.A., Keble College, Oxford; and David Pugh-Jones, C.A., F.S.I., Llandaff (Glamorgan), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Occurrence of Limestone of the Lower Carboniferous Series in the Cannock-Chase Portion of the South-Staffordshire Coal-field.' By George Marmaduke Cockin, F.G.S.

2. 'Liassic Dentaliidæ.' By Linsdall Richardson, F.G.S.

The following specimens, etc. were exhibited:—

Carboniferous Limestone from Fair Oak (Staffordshire) and fossils from the same, exhibited by G. M. Cockin, F.G.S., in illustration of his paper.

Liassic Dentaliidæ, collected on the new Honeybourne & Cheltenham Railway, exhibited by L. Richardson, F.G.S., in illustration of his paper.

Geological Survey of Alabama: Revised Map of the South-Eastern Part of the Cahaba Coalfield, on the scale of $1\frac{1}{2}$ inches to the mile, 1905, presented by the State Geologist of Alabama.

March 21st, 1906.

Aubrey Strahan, M.A., F.R.S., Vice-President, in the Chair.

Maurice Marcel Allorge, L. ès Sc., Demonstrator of Geology in the University of Oxford; Philip de Gylpyn Benson, B.Sc., Beechgrove, Sydenham Hill, S.E.; Andrew Bury, 1 Halifax Road, Ashton-under-Lyne (Lancashire); George William Edwards, Mining Engineer, Johannesburg (Transvaal); and Arthur Wade, 35 Hale Road, Liverpool, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Chalk and Drift in Möen.' By the Rev. Edwin Hill, M.A., F.G.S.

2. 'On the Relations of the Chalk and Boulder-Clay near Royston (Hertfordshire).' By Prof. T. G. Bonney, Sc.D., LL.D., F.R.S., F.G.S.

3. 'Brachiopod Homœomorphy: *Pygope*, *Antinomia*, *Pygites*.' By S. S. Buckman, F.G.S.

The following lantern-slides were exhibited:—

Lantern-slides, exhibited by the Rev. Edwin Hill, M.A., F.G.S., in illustration of his paper.

April 4th, 1906.

R. S. Herries, M.A., Vice-President, in the Chair.

Simeon Priest, 40 Church Terrace, Fenton, Stoke-on-Trent, was elected a Fellow; and Prof. John M. Clarke, LL.D., Director of the New York State Museum, Albany (N.Y.), U.S.A., and Dr. Jakob Johannes Sederholm, Director of the Geological Survey of Finland, Helsingfors (Finland), were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On a Case of Unconformity and Thrust in the Coal-Measures of Northumberland.' By Prof. G. A. L. Lebour, M.A., M.Sc., F.G.S., and J. A. Smythe, M.Sc., Ph.D.

2. 'The Carboniferous Succession below the Coal-Measures in North Shropshire, Denbighshire, and Flintshire.' By Wheelton Hind, M.D., B.S., F.R.C.S., F.G.S., and John T. Stobbs, F.G.S.[1]

The following specimens and lantern-slides were exhibited:—

Rock-specimens and lantern-slides, exhibited by Prof. G. A. L. Lebour, M.A., M.Sc., F.G.S., in illustration of his and Dr. Smythe's paper.

Carboniferous fossils, and lantern-slides, exhibited by Dr. W. Hind, B.S., F.R.C.S., F.G.S., and J. T. Stobbs, F.G.S., in illustration of their paper.

April 25th, 1906.

J. E. Marr, Sc.D., F.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Trilobites from Bolivia, collected by Dr. J. W. Evans in 1901–1902.' By Phillip Lake, M.A., F.G.S.

2. 'Graptolites from Bolivia, collected by Dr. J. W. Evans in 1901–1902.' By Ethel M. R. Wood, D.Sc. (Communicated by Dr. J. W. Evans, LL.B., F.G.S.)

[1] Withdrawn by permission of the Council.

3. 'The Phosphatic Chalks of Winterbourne and Boxford (Berkshire).' By Harold J. Osborne White, F.G.S., and Llewellyn Treacher, F.G.S.

The following specimens and map were exhibited :—

Trilobites and graptolites from Bolivia, exhibited by Dr. J. W. Evans, LL.B., F.G.S., in illustration of the papers by P. Lake, M.A., F.G.S., and Miss E. M. R. Wood, D.Sc.

Specimens of Phosphatic Chalk, exhibited by H. J. O. White, F.G.S., and Ll. Treacher, F.G.S., in illustration of their paper.

Geological Map of the Pretoria District, on the scale of 2 miles to the inch, by H. Kynaston, A. L. Hall, and F. A. Steart, presented by the Director of the Transvaal Geological Survey.

May 9th, 1906.

Aubrey Strahan, M.A., F.R.S., Vice-President, in the Chair.

William Atwood Tregaskis Davies, Bulong (Western Australia); and Walter Johnson, 9 Lavender Road, Clapham Junction, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The Chairman read, on behalf of the Council, a letter of condolence addressed by the Foreign Secretary to the Swiss Geological Society on the loss of Prof. Eugène Renevier, For. Memb. G.S., whose death was the result of an accident which took place only a few days before the proposed celebration of his professorial jubilee at Lausanne University.

The Chairman announced that the Council had resolved to award the Proceeds of the Daniel-Pidgeon Fund for 1906 to Miss Helen Drew, Newnham College, Cambridge, who proposes to examine the relationship of the Caradoc and Llandovery rocks in South Wales, between the Llandeilo and Fishguard districts.

The following communications were read :—

1. The Eruption of Vesuvius in April 1906.' By Prof. Giuseppe de Lorenzo, For.Corr.G.S.

2. 'The Ordovician Rocks of Western Caermarthenshire.' By David Cledlyn Evans, F.G.S.

The following specimens, etc. were exhibited:—

Photograph of Vesuvius and a map, exhibited by Prof. G. de Lorenzo, For.Corr.G.S., in illustration of his paper.

Specimens of dust, lava, and lapilli, etc., collected during the recent eruption of Vesuvius, and a photograph, exhibited on behalf of Arthur Collins by Prof. E. J. Garwood, M.A., Sec.G.S.

Specimens from the Ordovician rocks of Western Caermarthenshire and lantern-slides, exhibited by D. C. Evans, F.G.S., in illustration of his paper.

An associated set of teeth of *Ptychodus decurrens*, Ag. (var. *depressus*) *in situ* from the *Holaster-subglobosus* Chalk of Burham, near Rochester; and a quartzite-erratic (weighing 3 lbs.) from the Chalk of Messrs. Martin & Earle's Pit, Strood, exhibited by G. E. Dibley, F.G.S.

A copy of the rare 1844 edition of the 'Outline of the Geology of the Neighbourhood of Cheltenham, by R. I. Murchison,' exhibited by S. S. Buckman, F.G.S.

May 23rd, 1906.

R. S. Herries, M.A., Vice-President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Importance of *Halimeda* as a Reef-forming Organism; with a Description of the *Halimeda*-Limestones of the New Hebrides.' By Frederick Chapman, A.L.S., F.R.M.S., and Douglas Mawson, B.E., B.Sc. (Communicated by Prof. T. W. Edgeworth David, B.A., F.R.S., F.G.S.)

2. 'Notes on the Genera *Omospira*, *Lophospira*, and *Turritoma*; with Descriptions of New Species.' By Miss Jane Donald. (Communicated by Prof. E. J. Garwood, M.A., Sec.G.S.)

The Rev. H. H. Winwood, in exhibiting a series of water-colour drawings of Mexican scenery, said that these beautiful sketches were executed by Miss A. C. Breton, during a recent visit to Mexico; and, as the International Geological Congress was about to meet in that country, she thought that some of the Fellows might like to see them. They represented that line of active and extinct volcanos which stretches from the Gulf of Mexico on the east to the Pacific Ocean on the west, including Orizaba, Popocatepetl, Jurullo, and Colima. A short extract from the publications of the Mexican Geological Survey, translated by

Miss Breton, was read respecting the formation of Popocatepetl ('smoking mountain'), showing how the successive periods of volcanic energy may be marked (*a*) by a period of lava-flow, (*b*) by one of breccia, and finally (*c*) by one of ashes. The angles of slope of the volcanos were drawn to scale.

Prof. H. J. Johnston-Lavis exhibited upwards of forty lantern-slide views, to illustrate the late eruption of Vesuvius and its effects. Nearly all these were taken by the exhibitor, who explained the different phenomena portrayed.

In addition to the exhibits mentioned above, the following specimens, etc. were exhibited:—

Photographs exhibited by Prof. T. W. Edgeworth David, F.R.S., F.G.S., in illustration of the paper by Messrs. F. Chapman & D. Mawson.

Specimens, casts, and drawings, exhibited by Prof. E. J. Garwood, M.A., Sec.G.S., in illustration of the paper by Miss Jane Donald.

Halite in fine crystals, from a portion of the old cone ejected in the recent eruption of Vesuvius, exhibited by Prof. H. J. Johnston-Lavis, M.D., F.G.S.

June 13th, 1906.

Sir Archibald Geikie, D.C.L., Sc.D., Sec.R.S., President, in the Chair.

Joseph Davies, M.Australasian Inst.M.E., Mine-Manager, Bulong (Western Australia); James Francis, 26 Horton Road, Hackney, N.E.; Charles R. Hewitt, Mining Engineer, London Road, Derby; Owen Thomas Jones, Geological Survey of England, Blaenffynon, Newcastle Emlyn, S.O. (Caermarthenshire); Edward Arthur de Lautour, Mining Engineer, Magnet (Tasmania); John M. Milton, 8 College Avenue, Crosby, Liverpool; James Cowie Simpson, junr., The Avenue, 40 Greenhill Gardens, Edinburgh; and Richard Fletcher Whiteside, M.I.M.E., 62 Fern Grove, Sefton Park, Liverpool, were elected Fellows of the Society.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The following communications were read:—

1. 'Recumbent Folds produced as a Result of Flow.' By Prof. William Johnson Sollas, Sc.D., LL.D., F.R.S., F.G.S.

2. 'The Crag of Iceland—an Intercalation in the Basalt-Formation.' By Dr. Helgi Pjetursson. (Communicated by Prof. W. W. Watts, M.A., M.Sc., F.R.S., Sec.G.S.)

Mr. George Abbott, in exhibiting specimens and photographs of limestones showing band- and ball-structure, remarked that, at Fulwell-Hill Quarries, near Sunderland, some of the uppermost beds of the Magnesian Limestone presented this peculiarity. In places, the limestone contained as much as 97 per cent. of calcium-carbonate. The solid bands of limestone were from 1 to 7 inches thick, but the ball-layers were seldom more than 1 inch wide. This was a form of parallel banding that had no regular relation to the bedding, being sometimes at right angles thereto, and might even be seen passing uninterruptedly through several underlying bedding-planes. The speaker considered the structure to be the result of segregation after the formation of a mass of balls.

In addition to the exhibit mentioned above, the following specimen and lantern-slides were exhibited:—

Quartzose gravel from the upper part of the Reading Beds, Lane End (Buckinghamshire), exhibited by H. J. O. White, F.G.S.

Lantern-slides exhibited by Prof. W. J. Sollas, Sc.D., LL.D., F.R.S., F.G.S., in illustration of his paper.

June 27th, 1906.

Sir Archibald Geikie, D.C.L., Sc.D., Sec.R.S., President, in the Chair.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The President announced that the Foreign Secretary had, on behalf of the Officers and Council, addressed a letter of congratulation to Commendatore Prof. Arturo Issel, For.Corr.G.S., on the occasion of the fortieth anniversary of his professorate.

The following communications were read:—

1. 'Interference-Phenomena in the Alps.' By Mrs. Maria M. Ogilvie Gordon, D.Sc., Ph.D., F.L.S. (Communicated by Sir Archibald Geikie, D.C.L., Sc.D., Sec.R.S., P.G.S.)

2. 'The Influence of Pressure and Porosity on the Motion of Sub-Surface Water.' By William Ralph Baldwin-Wiseman, M.Sc., Assoc.M.Inst.C.E., F.G.S.

The following maps, drawings, etc., were exhibited :—

Drawings and lantern-slides, exhibited in illustration of the paper by Mrs. M. M. Ogilvie Gordon, D.Sc., Ph.D., F.L.S.

Maps and drawings, exhibited by W. R. Baldwin-Wiseman, M.Sc., F.G.S., in illustration of his paper.

Photographs illustrating the Geology of Perim Island, exhibited on behalf of Surgeon T. P. Thomson.

Geological Map of the British Islands, 1 inch = 25 miles (colour-printed); and Geological Survey of England & Wales, 1-inch Geological Map, n. s. Sheets 326 & 340.—Sidmouth (Drift), colour-printed, by H. B. Woodward, W. A. E. Ussher, C. Reid, & A. J. Jukes-Browne, 1906. Presented by the Director of H.M. Geological Survey.

Geological Map of parts of the Essequibo and Cuyuni Rivers (British Guiana), on the scale of half an inch to the mile, by J. B. Harrison & C. W. Anderson, 1905, presented by the Authors.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXII.

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